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ACQUIRING TRAVEL TIME AND NETWORK LEVEL ORIGIN-DESTINATION DATA BY MACHINE VISION ANALYSIS OF VIDEO LICENSE PLATE IMAGES

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OF VIDEO LICENSE PLATE IMAGES

by

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and

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INTRODUCTION

Video cameras and camcorders are extensively employed to collect a wide variety of traffic data. In certain instances, machine vision systems are used to facilitate the analysis of the video images; in most instances, video images are processed manually. The choice between manual and automatic image processing involves considerations of cost, the type of data being collected, and the use to which these data are to be put. In what follows, we categorize various applications of video image capture, providing examples of both manual and machine vision data processing.

CATEGORIZATION OF VIDEO IMAGE CAPTURE AND PROCESSING

The means by which video images are captured and processed may be categorized in a variety of ways. For the purposes of this paper, the following categorization is useful:

- Type of video instrument -- video camera or video camcorder.

  Video cameras are employed in fixed installations. The video signal (image) is transmitted by wire or fiber optic cable to a recorder, signal processer, and/or video monitor, depending on the application. Both black and white and color cameras are used. Black and white cameras require less ambient light than do color cameras and also cost less. Both color and black and white cameras can provide a higher resolution image than camcorders. The resolution of camcorders is limited by the image density capacity of the videotape, which in the Super VHS and III-8 formats is about 400 horizontal video lines. Video camcorders, however, are mobile survey instruments which can be set up wherever needed on a temporary basis.

- Type of installation -- fixed, vehicle-mounted, or tripod-mounted.

  The vast majority of installations use pole-mounted video cameras. Video images are transmitted to a central monitoring facility, from which operators can control the pan, tilt and zoom functions of the camera and its fixture. This type of installation is typified by wide area traffic surveillance systems. Other, less common, types of fixed installations include toll enforcement and signalized intersection monitoring and control.

- Type of image -- entire vehicle, selected element, or interior.

  The type of image acquired is dependent on the nature of the application. Wide area surveillance and intersection control use images of one or more vehicles and the roadway on which the vehicles are situated. Tracking of individual vehicles, for such applications as travel time or speed measurements, use license plate images. Occupancy studies require images of the interior of vehicles. Enforcement applications generally require both vehicle and license plate images.

- Type of image processing -- manual, automatic, semi-automatic.

  Most analysis of video imagery is done manually, although machine vision technology is being increasingly employed, often in conjunction with manual review. Wide area trafbc surveillance, the most common use of video, typically involves manual review of continuous imagery. Real-time applications require the instantaneous processing of license plate images that only machine vision systems can provide. Machine vision processing is also essential in video-based traffic signal control systems. In those instances where extreme accuracy is essential, such as in reading license plates for enforcement purposes, manual review of machine vision processed images is usually employed.

Machine vision video image processing systems are sub-categorized into two types for the purpose of this discussion: 1) systems that require an external signal to identify the presence of a vehicle or a vehicle license plate in a given video frame, and 2) self-triggering systems that can automatically identify the presence of a desired image feature, such as a license plate, and extract that image for further processing in real time without human intervention. Only self-triggering systems can be used to automatically process license plate images from videotape. A further refinement depends on whether or not image compression is used to increase the efficiency of image storage and transmission. Increasingly, image compression is used in toll and speed enforcement applications. [l]

As with all classification schemes, the one proposed above is incomplete and somewhat arbitrary, but it does provide a framework around which the most common applications of video technology to traffic analysis can be organized.

VIDEO APPLICATIONS

Traffic Surveillance

Video traffic surveillance systems are commonly used as a component of metropolitan area congestion and incident management programs. These systems employ pole-mounted video cameras whose output is transmitted to video recorders and monitors in a central traffic management facility. Image transmission is typically by means of fiber optic or coaxial cable, although wireless transmission is also employed. The images transmitted are of vehicles in the traffic stream and of the roadway over which the vehicles are passing. Analysis and interpretation of the video images are generally done manually. Machine vision systems are increasingly being employed to count and classify traffic, to monitor traffic flow characteristics, and to alert human operators to breakdowns in traffic flow.

Surveillance of vehicular movements at intersections makes use of pole-mounted video cameras whose output is transmitted by fiber or cable to video presence detectors linked to traffic signal controllers. The video images may also be transmitted to a traffic control center for manual review and interpretation.

Electronic Toll Collection Enforcement

Video cameras are installed at electronic toll booths to aid in the enforcement of toll collection. Images of both vehicles and license plates are captured. The license plates of toll violators are processed in real time by machine vision license plate readers and a video image of the offending vehicle is recorded. External triggers, such as treadle actuation, are typically used to identify those video frames containing images of vehicles. [l]

Site and Area-Wide Security Systems

Video cameras are installed at parking facilities, border crossings, and at entrances to and exits from cordoned zones and other secured areas to capture images of vehicles and vehicle license plates on a continuous basis. These images are typically transmitted by coaxial or fiber optic cable to a central monitoring facility, where they are processed manually or by machine vision. Both externally-triggered and self-triggered machine vision systems are employed.

Speed Violation Detection, Deterrence, and Enforcement

Video speed control installation employ video cameras mounted over the roadway which record license plate images that are transmitted by cable to self-triggered license plate readers. The video cameras are installed at the upstream and downstream ends of a section of roadway a known distance apart. Since the instant of time at which a vehicle's license plate is captured by each camera is known to the nearest fraction of a second, the time for a given vehicle to traverse the known distance can be accurately computed along with the vehicle's speed. Since this entire process is accomplished almost instantaneously, the speed and license plate number of vehicles exceeding a specified speed can be posted on a variable message sign for the operator of the offending vehicle to see as they leave the monitoring section.

If the speed violation evidence provided by the video/license plate reader system is to be used for enforcement purposes, a front-view color image of the offending vehicle is acquired synchronously with the exiting license plate image. These data can then be transmitted by microwave, cable, or other means to a police operations center for subsequent processing. [2]

Videologging

Van-mounted video cameras are used to acquire video images of roadway surface characteristics and roadside features as the van is driven at highway speeds over designated sections of the highway network. Video images are stored on videotape or optical disk in the van for subsequent manual or computer processing in the office. This system has generally replaced the use of emulsion film motion picture cameras.

Travel Time Studies

Tripod-mounted video camcorders positioned alongside the traveled way or on overpasses are used to record license plates at the beginning and end of measured segments of arterial highways or expressways. The instant of time, to the nearest 1/30th second, at which each license plate image is recorded is known. By matching the license plate of a given vehicle recorded at the beginning and end of the measured section, the time required by that vehicle to traverse this section -- and its mean speed -- can be determined precisely. Transcribing the video license plate image from videotape into a computer file can be done manually or by means of a self-triggered license plate reader. Manual transcription of an hour of videotape typically takes up to ten hours; a machine vision system can accomplish this same task in one-tenth of the time. [3]

Origin-Destination Surveys

Tripod-mounted video camcorders are used to acquire license plate data for two distinct types of origin-destination surveys -- external trip surveys at cordon line stations and micro-scale network or interchange flow pattern analyses.

Cordon Line Surveys

Video camcorders are used to record the license plates of vehicles passing cordon line stations. A sample of videotaped license plate images are transcribed into a computer file from which the mailing address of the registered owner of each sampled vehicle is obtained by matching the survey file against the state Motor Vehicle Registry file. A survey questionnaire is then mailed to each registrant's address.

Transcription of videotaped license plate images to computer file may be done manually or by using a self-triggered license plate reader. Manual transcription is very slow, as noted above, and considerable manpower is needed to achieve the rapid turnaround of files that **is** required for potential respondents to receive their questionnaires within the customary 5-day limit. [4]

Machine vision analysis can speed up the transcription process as much as ten-fold. However, considerable skill and experience in license plate videotaping is essential if the very low error rate required by the questionnaire mailing procedure is to be met by fill automatic machine vision processing. A semi-automatic procedure in which the internal trigger of the plate reader is used to isolate license plate images for subsequent manual processing will often prove to be the most efficacious compromise.

Micro-Scale Network Surveys

Video camcorders are positioned at strategic points on a highway network, freeway interchange, or complex intersection to record the license plates of passing vehicles. By matching the license plates recorded at logically associated points, patterns of movement through the network, as well as travel time patterns, can be determined. The videotaped license plate records can be manually transcribed; alternatively transcription can be accomplished much more rapidly using a self-triggered license plate reader.

In all but the simplest networks, it is necessary to acquire accurate license plate records for a high percentage of the vehicles passing each survey station. Therefore, as in the case of the cordon survey, the semi-automatic procedure based on the self-trigger ability of the license plate reader will be the most effective. [5]

Vehicle Occupancy

Video images of vehicle interiors are recorded using video cameras or camcorders. Manual review of the videotapes are then conducted to determine vehicle occupancy. There is, at present, no system available that is capable of automatically counting the number of occupants in a vehicle. It is feasible, however, to obtain synchronized images of a vehicle interior and that vehicle’s license plate. Such coupled images could be used for HOV lane planning and evaluation, and for HOV enforcement.

EXAMPLES OF VJDEO APPLICATIONS

Selected examples of video-based license plate surveys in which one or both of the authors have taken part are discussed below. The applications reported on here all involve the use of tripod-mounted video camcorders. In all but one instance -- the 1991 origin-destination cordon survey conducted by the Central Transportation Planning Staff (CTPS) of the Boston Metropolitan Planning Organization -- license plate matching using a self-triggered machine vision license plate reading system was employed.

The Boston Region External Cordon Survey

The Boston region external cordon survey was conducted in 1991 as part of a comprehensive origin-destination study designed to provide CTPS with data needed to update their regional transportation planning models. [3,4] Video camcorders mounted on highway shoulders or medians were used to record the license plates of vehicles moving at highway speeds past the cordon stations. A single camcorder was able to capture readable license plate images in two lanes of traffic. A sample of these videotaped images was transcribed manually to a computer file, which was used by the Motor Vehicle Registries in Massachusetts, New Hampshire and Rhode Island to determine the mailing address of each sampled registrant, to whom a mailback questionnaire was sent. Approximately 130,000 license plate records were processed in this manner.

Each hour of tape required ten hours of manual review to transcribe the one-in-five sample of video license plate images into a computer file. Transcription time can be reduced to well under two hours per hour of tape using currently available plate readers. Given that transcription errors must be kept to a minimum so as to avoid excessive numbers of mis-addressed questionnaires, the self-triggering function of the plate reader would be used to prepare a video screen display of license plate images which would then be read by a human operator and transcribed into a computer file. This procedure also allows the state in which the vehicle is registered to be easily read and transcribed along with plate number. This is essential if, as was the case with the Boston regional survey, out-of-state vehicles are included in the external survey.

Estimating Travel Times

Travel time is recognized as one of the most meaningful measures of congestion on urban arterials and expressways. [6,7,8] An efficient and accurate means of measuring travel time is by matching the license plates of a sample of vehicles at points in the traffic stream using video camcorders and automatic license plate readers. This method provides a statistically robust sample of travel times and a very rich set of detailed information regarding the movement of individual vehicles in the traffic stream.

The 1993 Federal Highway Administration/ Volpe National Transportation Systems Center Field Trials

An extensive series of field trials was conducted in 1993 under the auspices of the Federal Highway Administration for the purpose of comparing the effectiveness and cost of various methods of estimating travel times on urban arterial and freeway routes. The studies were designed by the Volpe National Transportation Systems Center and were conducted in Boston, Seattle, and Lexington, Kentucky, with cooperation of the traffic and transportation planning staffs of those cities' metropolitan planning organizations. [3,4,9, 10]

Sample results from the Boston and Seattle trials are provided below:

Boston, Southeast Expressway. Table 1 summarizes the analysis of travel time data recorded by camcorders positioned over the three northbound lanes of Boston's Southeast Expressway (I-93) at two stations 5.2 miles (8.3 km) apart. [3] This table is derived from a file of plate records that matched at the upstream and downstream stations and for which the instant of time at which each of the two matching plates was observed is known to the nearest 1/30 of a second. The data under the "Manual" rubric were obtained by viewing each frame of the videotape manually; the "Machine Vision" data were generated by running that same videotape through an automatic license plate reader, The "n" under the manual heading is essentially the actual number of vehicles that traveled between the upstream and downstream stations in the designated 15-minute interval. Consequently, with the exception of the 8:16-8:31 interval, s is the standard deviation around the true mean of the travel time of all vehicles moving between these two stations for that time interval and date.

The machine vision estimates of mean travel times and standard deviations are based on 15-minute sample sizes ranging from 5 to *26* percent (again, with the exception of the 8:16-8:3 1 interval). Yet, in every case, both the machine vision estimates of mean times and standard deviations are remarkably similar to those derived manually from the full population. Notably, the largest absolute difference between the population (manual) mean and the sample (machine vision) mean is only 4.4 percent. Even with a sample size of only 27 (7:46-8:01), the difference is 3.5 percent.

Seattle, State Route 520. Figures 1 and 2 illustrate the pattern of travel times over a 15-minute interval for a one-mile (1.6 km) section of State Route 520 in Seattle, Washington. [1 l] Figure 1 is derived from the manual, frame-by-frame, analysis of videotape; Figure 2 is based on data generated by running this same videotaped through an automatic license plate reader. The pattern in Figure 2 based on the machine vision sample data matches closely the full-population data pattern in Figure 1. Each observation in Figure 2 is displaced downward by 10 seconds due to different start-time index procedures used in the two analyses, In addition to providing very robust estimates of mean travel time for even very short time intervals, the richness of these data offers an opportunity to observe the time dynamics of stream flow in a way that no other method of travel time estimation can do.

Evaluating High Occupancy Lane Performance

The video/machine vision license plate matching techniques used in the travel time studies reported on above can also provide detailed travel time measurements useful in evaluating the effectiveness of high occupancy vehicle (HOV) lane use, These techniques were employed recently to compare average travel times experienced by motorists using HOV and adjoining general purpose lanes on two facilities in Seattle. [12,13] Inbound morning peak period traffic on State Route 520 between 92nd Avenue and 74th Avenue [1.7 km(l.1 mi)] and outbound afternoon peak period traffic on I-5 from 117th Street to 185th Street [5.8 km (3.6 mi)] were monitored for four days in June, 1995. A summary of a portion of the results of these analyses is presented in Table 2. As can be seen, the time savings enjoyed by motorists using the I-5 HOV facility is quite substantial; general purpose lane travel times over the test section ranged from 1.6 to 2.1 times that of HOV lane travel times.

Microscale Origin-Destination Studies

The video/machine vision license plate matching techniques used to measure travel times can also be employed to determine patterns of movement within highway networks and through complex freeway interchanges. Applications of this technique in Great Britain have employed as many as 48 simultaneous data collection stations. [14] Experience in the United States, where the extreme individuation of license plates make automated reading of license plates more diicult than in Europe, is somewhat more limited. Two recent instances of the use of video/machine vision license plate microscale O-D studies were at the interchange of I-4 and I-275 in Tampa and on the arterial road system serving serving Houston's Intercontinental Airport.

Tampa, I-4/I-2 75 Interchange

The Tampa study was conducted in collaboration with the Center' for Urban Transportation Research of the University of South Florida as a component of CUTR'S Intelligent Transportation Systems Field Demonstration of Automated Video-Based Traffic Data Collection project. [15,161 The positioning of camcorders at the I-4/I-275 interchange in Tampa is shown in Figure 3. Morning peak period traffic entering the interchange on the westbound lanes of I-4 was videotaped at stations 1 and 2; traffic on the southbound lanes of I-275 was videotape at stations

3 and 4. Traffic exiting at Ashley Street was taped at stations 5 and 6. Camcorders l-5 were set to record license plates, as were two other camcorders positioned over the Southbound lanes of I-275 at Livingston Avenue, ten miles north of the 1-275/I-4 interchange. Camcorder 6, at Ashley Street, was positioned to record the number of occupants in each vehicle passing that site.

The videotaped license plate images were extracted and analyzed by a machine vision system very similar to the one used in the VNTSC/FHWA studies summarized above. Both travel.times and the distribution of movements between stations were determined. Table 3 illustrates one of the travel time summaries. Table 4 summarizes the resulting origin-destination data for one time period.

Houston Intercontinental Airport Arterial Access Roads

The Houston Intercontinental Airport study was designed to determine the patterns of movement on the arterial highways in the immediate vicinity of the airport. [5] Of particular interest to the airport authorities was the proportion of traffic using these roadways that had origins or destinations at the airport terminal and the proportion that was using these roadways as a means of avoiding congestion at other points in the highway network. Both these microscale origin-destination patterns and associated travel times were developed by means of machine vision analyses of camcorder license plate images. Figure 4 depicts the roadway layout and camcorder stations for the midday and p.m. peak periods. Table 5 summarizes the resulting matrix of origins and destinations for the p.m. peak period.

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Table 1. Comparison of 15-minute Average Travel Times, Southeast Expressway Northbound, Boulevard Street Extension to Boston Street, as calculated by Manual and Machine Vision Analysis of Videotape License Images

Time Period	Manual				Machine Vision					
a.m.	t,min	S,min	Std. Error of Est., %	n	t,min	S,min	Std. Error of Est., %	n	t_m-t_{mv}, sec.	t_m-t_{mv}, %
6:31-6:46	11.77	0.82	7.0	382	11.25	0.97	8.6	61	0.52	4.4
6:46-7:01	12.37	0.68	5.5	391	12.55	1.28	10.2	64	-0.18	-1.5
7:01-7:16	12.99	0.70	5.4	382	12.65	0.97	7.7	101	0.34	2.6
7:16-7:31	13.73	0.90	6.6	473	13.25	1.13	8.5	87	0.48	3.5
7:31-7:46	14.62	0.80	5.5	481	14.10	1.08	7.7	78	0.52	3.6
7:46-8:01	14.95	0.73	4.9	530	15.47	1.00	6.5	27	-0.52	-3.5
8:01-8:16	15.96	0.77	4.8	353	16.07	0.90	5.6	45	-0.11	-0.7
8:16-8:31	17.16	0.93	5.4	87*	17.83	1.97	11.0	51	-0.67	-3.9

*Limited n due to camcorder malfunction.

Source: Shuldiner [3].

Table 2. Comparison of Travel Times on HOV and Adjacent General Purpose Lanes: I-5, Seattle, 4:00 p.m. - 6:00., June 22, 1995.

	LANE						
Time, p.m.	General Purpose			HOV			t_{gp} / t_{HOV}
	t, sec.	Std Dev. sec	n	t, sec.	Std. Dev. sec	n	
4:00 - 4:15	650.4	60.8	69	318.8	26.2	85	2.0
4:15 - 4:30	638.6	41.9	58	307.5	45.9	85	2.1
4:30 - 4:45	607.3	40.7	66	333.2	24.8	87	1.8
4:45 - 5:00	566.5	25.5	24	363.7	13.7	52	1.6
5:00 - 5:15	612.6	19.4	76	392.7	29.7	67	1.6
5:15 - 5:30	671.1	47.9	68	362.4	34.6	77	1.9
5:30 - 5:45	686.2	40.3	55	330.9	17.9	48	2.1
5:45 - 6:00	526.1	45.8	60	284.9	18.3	57	1.8

Source: Shuldiner, D'Agostino and Woodson [13]

Table 3. Mean Travel Times and Standard Deviations by 30-minute Intervals: I-4/I-275 Interchange, Tampa.

Time (AM)	# of Matched Plates	Mean Travel Time (sec)	Standard Deviation (sec)	Coefficient of Variation (%)
7:15 - 7:45	58	120.1	17.0	14.2%
7:45 - 8:15	79	150.4	10.4	6.8%
8:15 - 8:45	127	154.9	11.2	7.2%
8:45 - 9:15	99	155.7	6.4	5.2%

Source: Transfomation Systems, Inc. [16]

Table 4. Origin-Destination Summary: I-4/I-275 Interchange, Tampa

Camera Pair (I-275N) (I-4 W)	# of Vehicles at First Camera Location	# of Vehicles at Last Camera Location	Actual # of Matched License Plates	Normalized Number of Matched Vehicles	Percentage of Vehicles Turning	Percentage of Through Traffic
1 to 5 **(I-275 N)**	2,776	2,417	363	1,366	49%	67%
2 to 5	2,465	2,417	113	370	15%	
3 to 5 **(I-4 W)**	3,448	2,417	142	396	11%	89%
4 to 5	2,881	2,417	97	285	10%	

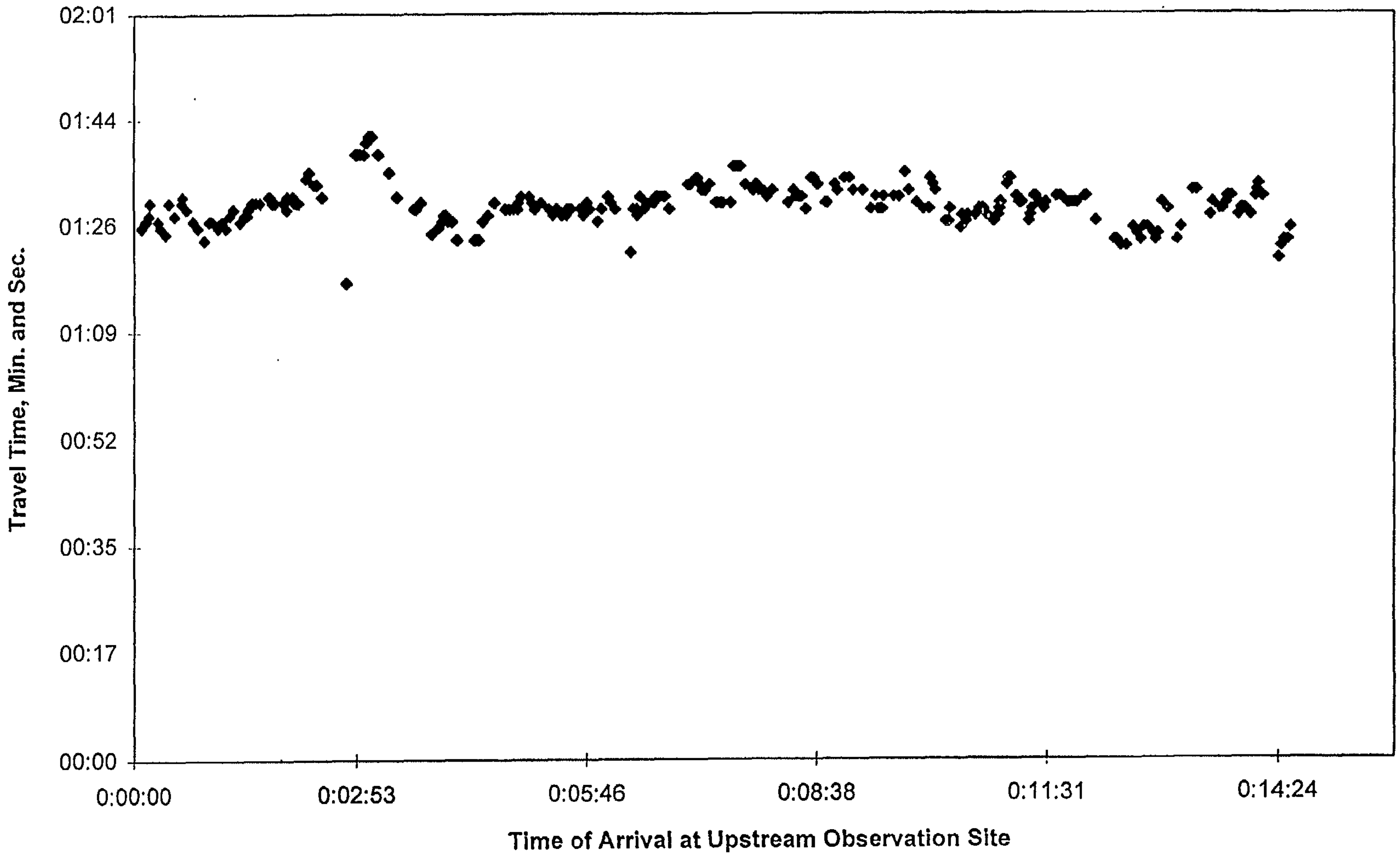
Source: Transfomation Systems, Inc. [16]

Table 5. Traffic Origins and Destinations, P.M. Peak Movements: Houston Intercontinental Airport

To / From	Station 1	Station 2	Station 3	Station 4	Station 5	Station 6	Station 7	Station 8	Airport & Greens District	Totals
Station 1	*32 % from Station 1 was through traffic to Will Clayton*			39	86	59			308	453
Station 2	*29 % from Station 2 was through traffic to Will Clayton*			385	624	334			2,370	* 3,328
Station 3	*15 % from Station 3 was through traffic to Will Clayton*			220	354	219			3,334	* 3,907
Station 4										
Station 5										
Station 6										
Station 7		1,723	2,149	380	602	295			4,579	5,476
Station 8		544	147	159	214	148			981	1,343
Airport & Dist.				1,441	2,402	1,348				* 3,750
Totals				2,046	* 3,380	* 1,901			* 5,704	*10,985

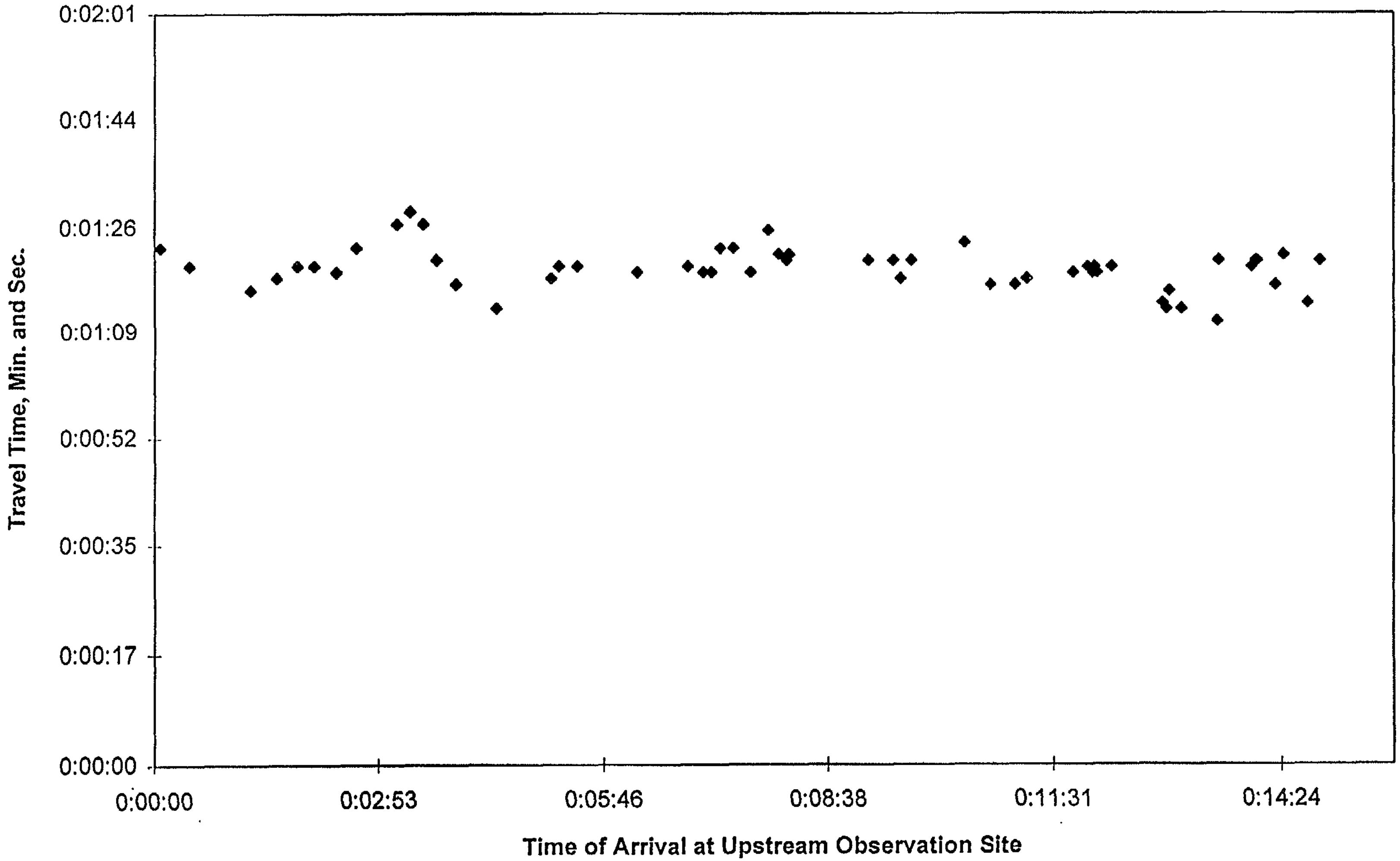
Source: Transfomation Systems, Inc. [5]

Figure 1. Array of Travel Times for Vehicles Entering in Lane 1 and Exiting in Lane 1 Ordered by Time of Arrival at Upstream Observation Site: Manual Analysis: SR 520, Seattle



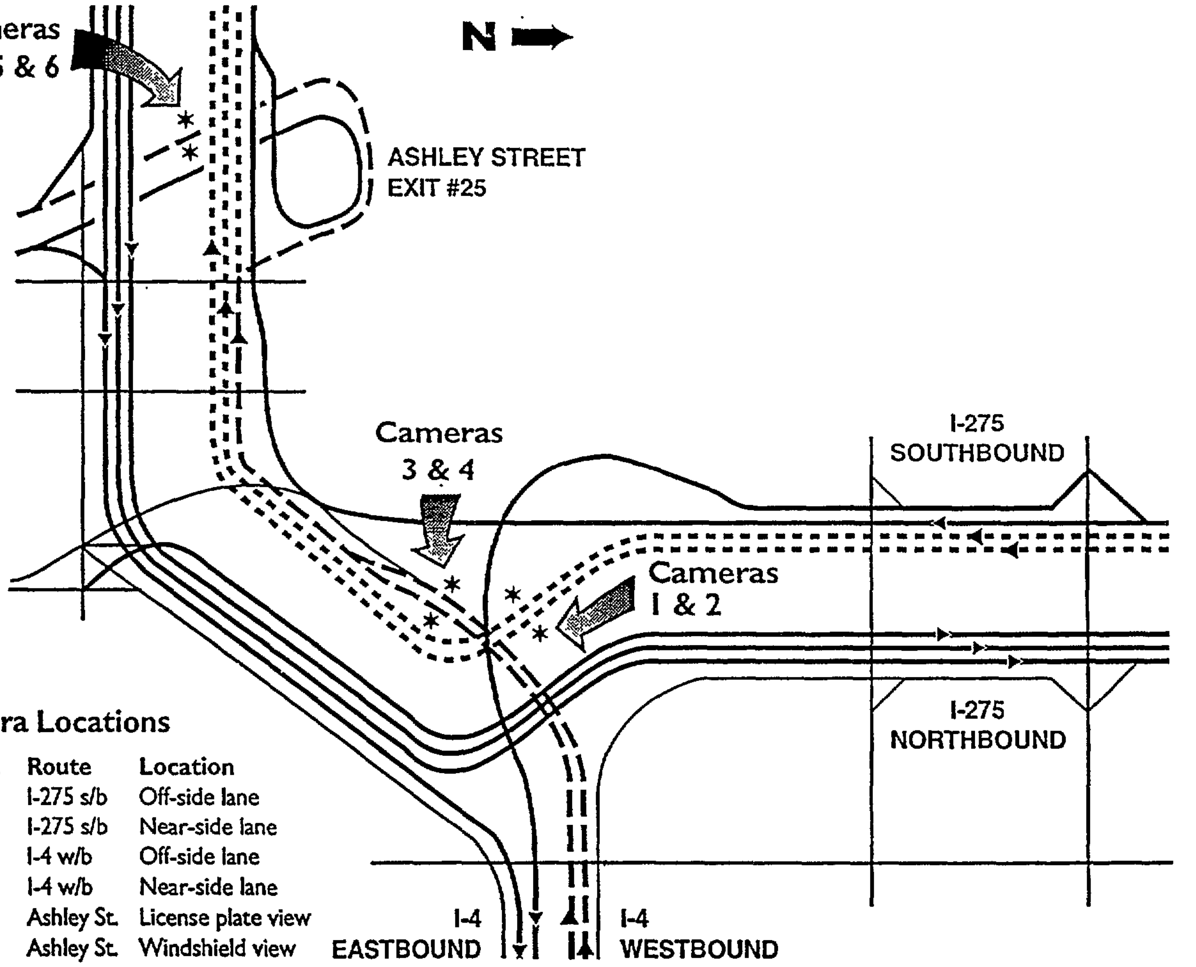
Source: Shuldiner [11]

Figure 2. Array of Travel Times for Vehicles Entering in Lane 1 and Exiting in Lane 1 Ordered by Time of Arrival at Upstream Observation Site: Machine Vision Analysis: SR 520, Seattle



Source: Shuldiner [11]

Figure 3. Freeway Interchange Layout and Video Camcorder Locations: I-4/I-275, Tampa.

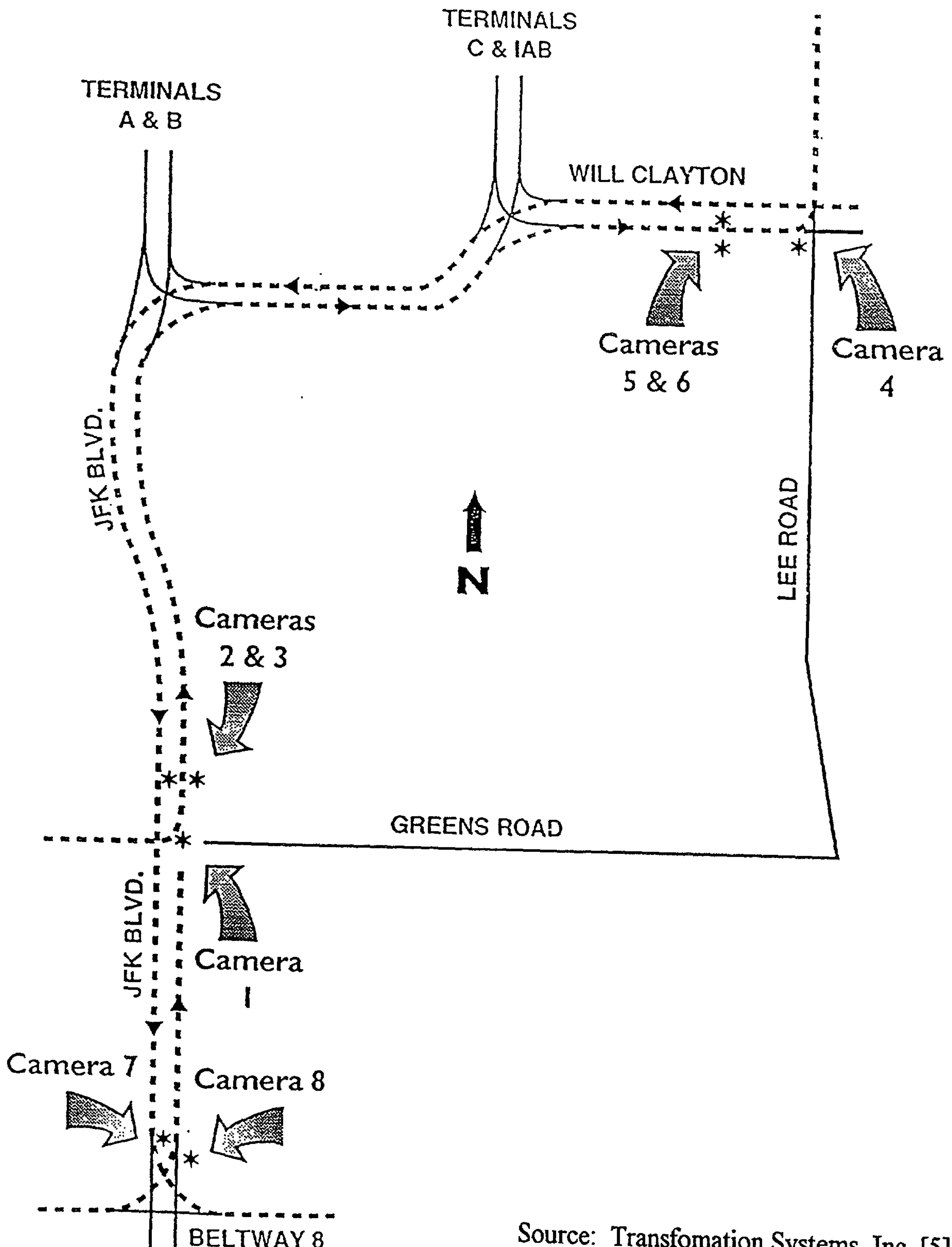


Camera Locations

Station	Route	Location
#1	I-275 s/b	Off-side lane
#2	I-275 s/b	Near-side lane
#3	I-4 w/b	Off-side lane
#4	I-4 w/b	Near-side lane
#5	Ashley St.	License plate view
#6	Ashley St.	Windshield view

Source: Pietrzyk [15]

Figure 4. **Arterial Street Layout and Video Camcorder Locations, P.M. Peak Period: Houston Intercontinental Airport**



Source: Transfomation Systems, Inc. [5]

USE OF ADVANCED TECHNOLOGY IN HOV LANE ENFORCEMENT

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ABSTRACT

This paper assesses technologies that may be applicable for improving the effectiveness of high-occupancy vehicle (HOV) lane enforcement, and describes a test application that is being conducted on the East R.L. Thornton Freeway (I-30) Contraflow HOV Lane in Dallas, Texas.

The Texas Transportation Institute has identified and investigated several technologies that potentially could improve the safety and cost-effectiveness of enforcing HOV facilities. Several technologies, including video, automatic vehicle identification and machine vision, were subjectively evaluated on their ability to automatically determine vehicle occupancy. Based upon these subjective evaluations, researchers decided to further investigate the use of video in HOV lane enforcement.

A demonstration test and subsequent video analyses determined that current pattern recognition algorithms would not be sufficient to automatically determine vehicle occupancy. Results of the demonstration test did reveal that high-quality video used in conjunction with automatic license plate readers could be very useful in making the HOV enforcement process semi-automatic.

A video-based review and enforcement system is currently in process with a one-year operational test on the East R.L. Thornton Freeway HOV Lane. The results of the operational test will be used in determining whether video technology may be applied to existing HOV lanes in urban areas or other future HOV lanes in Dallas.

INTRODUCTION

Adequate enforcement of vehicle occupancy restrictions plays a key role in the success of high-occupancy vehicle (HOV) facilities. A high number of unauthorized HOV lane users (e.g., single-occupant vehicles) can create congested traffic conditions on an HOV lane, thereby decreasing travel time savings and reliability incentives for commuters to carp001 or use public transit. Unauthorized HOV lane users also frustrate other motorists in the HOV lane and the general-purpose freeway lanes, who dislike the “cheating” drivers. This motorist frustration is then aimed at enforcement personnel that operate the HOV lane or the public agencies that constructed the lane. The lack of public support due to poor or ineffective enforcement has closed several HOV projects in the Unites States (1).

The Texas Transportation Institute (TTI) initiated a research project in late 1993 to investigate the use of advanced technologies in HOV lane enforcement. The Texas Department of Transportation, Dallas Areas Rapid Transit, Federal Highway Administration, and Federal Transit Administration sponsored the project, which is aimed at identifying technologies to improve the safety and cost-effectiveness of HOV lane enforcement. The study's objectives are to identify the most promising technology and perform a one-year operational test on the East R.L. Thornton (I-30), or ERLT, HOV lane in Dallas, Texas. The results of the operational test will be useful for improving enforcement procedures on future HOV lanes in Dallas and on existing HOV lanes in other urban areas.

Paper Organization

This paper provides a summary of the research conducted for this HOV enforcement project, and describes details of the operational test that will begin in mid-1996. The organization of the paper is as follows:

Background

This section contains a summary of the literature review and presents findings in regard to available technologies for HOV lane enforcement.

Demonstration Test

This section provides a discussion of the results of a small-scale demonstration test of video technology. The test was conducted to determine whether further operational testing of video was warranted.

HOV Lane Enforcement and Review (HOVER) System Design

This section contains a description of the equipment and procedures that will be used in a one-year operational test of a semi-automated review and enforcement system. The test will be conducted on the ERLT HOV Lane in Dallas, and should begin in mid-1996.

BACKGROUND

This section of the paper presents background information on HOV lane enforcement and the capability of various technologies to automate the enforcement process. A literature review was conducted for the Dallas HOV project, and several innovative enforcement techniques are described in the following sections. Several research laboratories and technology vendors were contacted to gather information about video, automatic vehicle identification (AVI), and machine vision technologies. A review of available technology is also summarized in the following sections.

Literature Review

The following paragraphs present a summary of literature related to innovative techniques for improving HOV lane enforcement. A more complete discussion may be found in (2).

In 1978, Miller and Deuser (3) suggested the use of several techniques to improve HOV lane enforcement, including photographic instrumentation, mailing of citations, the use of para-professional officers (trained technicians), remote apprehension, and mass screening of license plates to identify habitual offenders. Several of the techniques, like mailed citations or warnings and remote apprehension, are now commonly employed on HOV projects; however, the other techniques have not been widely used.

On several HOV lanes, state law permits the mailing of citations to the registered owner of vehicles violating an HOV occupancy restriction. The mailed citations are based upon the police officer's visual contact with an violating vehicle. This technique was used on the Southeast Expressway in Boston, Massachusetts, because police officers could not safely escort HOV lane violators across several lanes of congested freeway traffic (3). The Virginia Department of State Police also has the ability to mail citations to the registered owners of vehicles observed violating HOV occupancy restrictions (4).

Another technique that has been employed at several locations is mailed warnings or information. This techniques is geared more towards education, and can be used where state law does not permit mailed citations. Repeat violators on the priority lanes of the San Francisco-Oakland Bay Bridge were sent warnings and information on the possible consequences of their violation (3). The response to the letters was considered good, with only 10 percent of the repeat violators observed again in the priority lanes. The HERO telephone hotline program in Seattle, Washington, permits motorists to report HOV lane violators (5). HOV educational material and warnings are sent to the registered owners of violating vehicles. Before-and-after studies along I-5 in Seattle indicated the HERO program had reduced violation rates by approximately 33 percent. A similar telephone hotline program has been developed in Northern Virginia, where information and warnings are sent to the registered owner of violating vehicles (4).

In 1990, the California Department of Transportation tested the use of video in HOV lane surveillance and enforcement (6). The study examined the use of video cameras and recorders in determining vehicle occupancy, documenting violator identity, and assisting in the enforcement of HOV lanes. There were four typical camera positions used throughout the study: a long-distance (0.4 km, or 0.25 mi.) oncoming view, a close-up view of the license plate, an oblique view downward into the passenger seat, and a side eye-level view into the vehicle.

The study reported the following about the use of video in HOV lane enforcement:

- Video cameras operating alone cannot identify the number of vehicle occupants with enough certainty to support mailed citations for HOV lane restrictions. The video tests had a false alarm rate of 2 1 percent (2 1 percent of vehicles identified by videotape reviewers as violators actually had the required number of occupants). Small children or sleeping adults in the rear seat were not captured by the video camera, and poor light conditions, glare, and tinted windows compounded the problem of viewing passengers in the interior of the vehicle.

- The use of video as a real-time enforcement aid appears to be limited to those locations lacking enforcement areas for officer observation. At these locations, a video camera could be safely positioned to assist a downstream officer in determination of vehicle occupancy. The study noted, however, that an officer stationed beside an HOV lane in an enforcement area was in a much better position to observe violations than an officer at a remote video monitor.

- Video provides a freeway and HOV lane monitoring tool that is potentially more consistent and accurate than existing techniques for documenting vehicle occupancy.

Technology Review

Many electronics vendors and research laboratories were contacted about technologies that could be used to automatically determine vehicle occupancy. The results of these discussions are summarized below by the three applicable technologies: video, AVI, and machine vision.

Video

Video already has numerous applications in transportation, including freeway surveillance and monitoring, various enforcement activities, and data collection. Coupled with options like a zoom lens, automatic exposure control, high shutter speeds (up to l/10,000 second), and light overload capability, current video cameras can capture high-quality images of a traveling vehicle (speeds up to about 100 kph, or 60 mph) from a distance in low-light conditions.

The most common application of video technology is freeway surveillance and monitoring. The cameras used for incident detection and verification need only to distinguish vehicle breakdowns or accidents, which typically do not require the use of high-resolution color cameras. Video cameras are also used by several agencies for enforcement of traffic signals and rail-highway grade crossings, although these applications typically employ a 35-mm camera that is triggered by an inductance loop or radar when a violation occurs.

A video enforcement system would consist of several video cameras on the HOV lane controlled and monitored from a remote location. A single officer located at a downstream enforcement station could have several minutes to respond to a possible violation, or an officer could be teamed with a trained technician that would alert the officer of any possible violations. The downstream officer would be responsible for verifying the HOV lane violation and issuing a citation in states that do not yet allow mailed citations.

The operating costs associated with a video enforcement system would be lower than manual enforcement, and the safety of police officers would be improved. However, video cameras cannot observe small children or sleeping adults in the rear seat. Poor light conditions, glare, and tinted windows compound the problem of viewing passengers in the interior of the vehicle. Some of these problems can be addressed with supplemental lighting, high-end camera specifications, and image enhancing tools. Video surveillance of an HOV lane would be no more intrusive than officer observation. However, surveillance of vehicle interiors could potentially have poor public acceptance because of privacy issues.

Automatic Vehicle Identification

AVI systems are becoming increasingly common on toll facilities where a "toll tag" is used to debit a motorist's existing account. There are several basic elements typical of AVI systems, including a vehicle-mounted transponder (tag), a roadside reader and control unit, a central computer that processes and stores transponder-reader interactions, and an enforcement system.

There are numerous applications of AVI systems across the United States, and most of the systems are utilized for electronic toll collection purposes. An AVI system was considered in the initial stages of the Houston transitway system development, but was later dropped from consideration when it became apparent that car-pools would be regular users of the transitway system (7). Consequently, the AVI concept has never been used or tested on HOV facilities. For carp001 identification purposes, however, several AVI vendors indicated that multiple transponders could be read from a single vehicle (e.g., transponder for each car-pool member).

An AVI enforcement system would require that all vehicles using an HOV lane be authorized users with an identification transponder(s) in their vehicle. Two basic options exist for registering car-pools and issuing AVI tags: requiring that only one transponder be registered for each car-pool, or requiring that each carp001 member register a transponder.

Enforcement of an HOV lane would be accomplished by monitoring the transponder-reader interactions. If the required number of transponders are not read from a single vehicle, a visual description of the vehicle is obtained via video or still-frame pictures. A downstream officer would then be responsible for verifying the violation. If authorized vehicles are found in violation of the vehicle occupancy requirements, the contraflow lane privileges of those persons registered to the transponder(s) could be revoked for a stipulated time period or indefinitely. Warnings or information packets could be given to first-time offenders or car-pools without transponders.

The registration and authorization process associated with an AVI system would seem to discourage current and potential users of the HOV lane. The Houston transitway system originally operated as authorized vehicle lanes, but the discontinuance of the authorization requirement prompted a substantial increase in car-pool utilization of the transitway system. For example, peak period carp001 volumes on the Katy Transitway had increased by approximately 1,400 vehicles after one month and almost 2,000 vehicles one year after discontinuance of the authorization requirement (8). The privacy of authorized vehicle occupants can be protected through the use of confidential transponder-reader interactions commonly utilized at toll facilities.

Machine Vision

The concept of machine vision for HOV lane enforcement encompasses those technologies that utilize electro-optical i&red sensors and/or image processors with pattern recognition to remotely identify and distinguish individual vehicle occupants. Machine vision would theoretically be capable of distinguishing a live person from a mannequin by heat or heat differentials measured with an infrared sensor. Using pattern recognition, machine vision could theoretically distinguish a sleeping adult in the rear seat from a warm rear axle.

Forward-looking infrared radar (FLIR) and thermal imaging are established machine vision technologies that have been proven in military surveillance and reconnaissance applications, but are just beginning to make the transition to non-military applications. Several research agencies and laboratories were contacted about machine vision technologies, and most could only propose or suggest some combination of infrared, radar, and electro-optical machine vision for HOV lane enforcement. Many researchers indicated that the presence of window glass severely limited the usefulness of commercially available infrared image sensors for HOV passenger identification and verification, since infrared energy emitted by a warm body is dissipated by the window glass.

A Georgia Tech researcher suggested the use of a radiometer, and reported on a test that evaluated a radiometer and a FLIR device. According to the researcher, the test successfully demonstrated the potential usefulness of radiometer techniques in HOV identification and verification, whereas the FLIR device could not accurately distinguish vehicle occupants. The radiometer device requires extensive development before a test application could be considered.

This alternative would be considered favorably if machine vision equipment were commercially available for field testing. A machine vision alternative would not require the registration of car-pools or carp001 members, and could potentially be more accurate than video techniques.

DEMONSTRATION TEST

Based upon the technology review, it was decided that a small-scale test of current video technology should be conducted. Transformation Systems, Inc. (Transfo) of Houston, Texas was contracted to perform a demonstration test with the following objectives:

1.) Identify optimal camera mounting arrangements, lens and lighting configurations;
2.) Identify the effects of low light conditions and tinted windows on video effectiveness; and,
3.) Identify the potential for using pattern recognition to automate vehicle occupancy determination.

The demonstration test was performed on the North Freeway (I-45) HOV lane in Houston during the early morning and afternoon of normal weekday traffic. The video was later analyzed by Transfo, Computer Recognition Systems, Inc. (CRS), Symond Travers Morgan Limited (STML), and TTI.

Results

The demonstration test identified optimal camera mounting arrangements, lens and lighting configurations that will be evaluated and refined in a one-year operational test. General details of the demonstration test results are provided here, as the specific design of the enforcement system may be changed or refined as the operational test proceeds in Dallas.

Several camera angles are required for determination of vehicle occupancy, with the most important angles including a close-range front windshield view and a passenger-side window view. Proper placement of the cameras was shown to reduce glare and other lighting problems previously encountered in other video surveillance projects.

Directional lighting was used to illuminate vehicle interiors in low-light conditions, and proved to be satisfactory for determining vehicle occupancy in early morning hours. When passing through the directional lighting, HOV lane users saw a brief flash of light. Some drivers were distracted by the light, but most drivers appeared oblivious to the directional lighting. The supplemental lighting did penetrate some lightly-tinted widows during low-light conditions, but tinted windows made it very diicult to capture clear images of occupants with the presence of abundant natural light.

TTI reviewed several hours of the video to determine the ability to see inside vehicles' passenger compartments. The results of their video review indicated that during ideal lighting conditions (early morning with minimal glare, directional lighting), the human reviewers could not positively determine vehicle occupancy on approximately 5 percent of the vehicles in the HOV lane. During less-than-ideal lighting conditions (high light, glare) later in the day, the ability to see vehicle compartments decreased; as a result, vehicle occupancy could not be positively determined on about 25 percent of all HOV lane users.

Transfo, CRS, and STML analyzed the video to examine the potential of using pattern recognition to automatically detect vehicle occupancy. The results of their analysis indicated that automatic vehicle occupancy detection is very difficult using video-based machine vision technology. Several problems with using video-based machine vision technology for automatic occupancy detection were noted:

- Providing adequate lighting in the vehicle compartment can be accomplished, but is difficult without distracting the driver. Infrared or amber-colored light was suggested to lessen driver distraction.

- Locating the various vehicle passenger compartments automatically is difficult because of the wide variety of vehicle shapes, sizes, and windshield/window designs.

- Performing automatic image analysis is very challenging with "unconstrained scenes," or the wide variety of passenger positions and confusing features like headrests or hats that can exist within the vehicle compartment.

Transfo, CRS, and STML proposed that there are at least two possible approaches to advance the use of video in HOV lane enforcement. A short-term solution could utilize vehicle image capture, an automatic license plate reader, and a semi-automatic review system. This technique would require enforcement personnel to manually review some vehicle compartment images before performing a traffic stop. A long-term approach would develop an automated approach that would address many of the pattern recognition problems noted earlier.

Because of the required development time and high uncertainty of results with developing a fully automated system, TTI researchers and project steering committee members selected a semi-automatic enforcement system for immediate operational testing. The conceptual design for a semi-automatic enforcement system is presented in the next section.

HOV LANE ENFORCEMENT AND REVIEW (HOVER) SYSTEM DESIGN

TTI is currently working with Transfo in designing and installing a semi-automatic review and enforcement system (HOVER) on the ERLT HOV lane in Dallas. The system will be used to assist law enforcement personnel in determining compliance with vehicle occupancy restrictions. The following sections describe the HOVER system's functional capabilities of the operating procedures.

Functional Capabilities

The enforcement system will perform the following basic functions:

1.) Collect and transmit video images of vehicle license plates and vehicle compartments for all HOV lane users to a remote computer workstation.
2.) Perform automatic license plate character recognition on the license plate video image.
3.) Synchronize the captured video images of vehicle occupants with license plate numbers.
4.) Search a license plate data base containing vehicle occupancy histories and, based upon failure to meet set criteria, display the vehicle license plate number and vehicle compartment images on a computer monitor for review and enforcement purposes.

The following sections discuss each of the enforcement system's functional capabilities.

Collection and Transmission of Video Images

Several color CCD cameras will be used to capture front and side images of vehicle compartments and license plates. The cameras will be capable of operating in low-light conditions with supplemental lighting as required. The cameras will also be equipped with filters to reduce or eliminate glare, and be enclosed within a sealed environmental housing.

The CCD cameras will collect synchronized images of vehicle license plates (front or rear) and the respective vehicle's interior compartment. Two different camera viewing angles will be used to collect vehicle compartment images: a front "heads-on" view and a side view. The images will be transmitted by spread spectrum or microwave to an enforcement workstation located several miles down the freeway corridor.

Automatic License Plate Recognition

Transfo will be installing au automatic license plate recognition system manufactured by CRS that works in conjunction with the CCD cameras. The license plate recognition system will output license plate characters to a data base, and the license plate record will also include a time and date stamp, a confidence level in the license plate record, and the corresponding license plate image for manual inspection. The software will also be capable of liing a license plate record to several images of the respective vehicle's interior compartment.

License Plate/Vehicle Occupancy History Data Base Searching

Once the video cameras are installed and operating, TTI will develop a data base of license plate records and corresponding vehicle occupancies from video collected by the HOVER system along the ERLT HOV lane for one month. The license plate and vehicle occupancy data base will be capable of being updated on a continuing basis by the Dallas Area Rapid Transit (DART) as they operate the enforcement system. Transfo and CRS are developing a software interface that permits the license plate/vehicle occupancy data base to be searched to match a license plate record collected by cameras in real-time. The computer software will also be capable of comparing the matched record's vehicle occupancy history to set criteria, and upon meeting set criteria, releasing the video image for permanent storage. If a license plate is not in the data base or does not meet set criteria., the license plate record and all vehicle interior compartment images will be displayed on a monitor for review by enforcement personnel.

The automatic license plate recognition, license plate/vehicle occupancy history data base searching, and display of license plate records and vehicle interior video images will be integrated into a single computer workstation interface. The computer workstation interface will be Windows--based, graphically-oriented and menu-driven.

Because license plate information will be maintained in the data base, there will be multiple layers of security to protect the privacy of this information. The license plate data base and incoming license plate records will be protected from insecure access through data encryption and password protection.

Operating the Enforcement System

A conceptual sketch of the HOVER system is shown in Figure 1. Once the HOVER system is in place, no more than one police officer should be required to enforce the HOV lane. The police officer will be located between one to two miles downstream of the video cameras, and will review the video images of vehicles that are not contained in the carpool data base. If the officer can confirm the vehicle being reviewed is a valid car-pool, the officer can, with a single keystroke, add the vehicle's license plate to the carp001 data base.

If the vehicle is not in the car-pool data base and the officer can not confirm that it meets minimum occupancy requirements, the officer can note the license plate and vehicle description. The officer then has approximately one to two minutes to move into an enforcement position for the suspected HOV lane violator.

Video records will be kept of all videos, allowing video records to be reviewed off-line, and permitting the carp001 data base to be updated at frequent intervals. Like the license plate information, the video records will be considered confidential information and will be password protected and kept in locked storage.

Officers with the DART will provide feedback about the enforcement procedures on a continuing basis. The officer's feedback and comments will be used to refine the procedures, and will ultimately determine the usefulness of video in HOV lane enforcement.

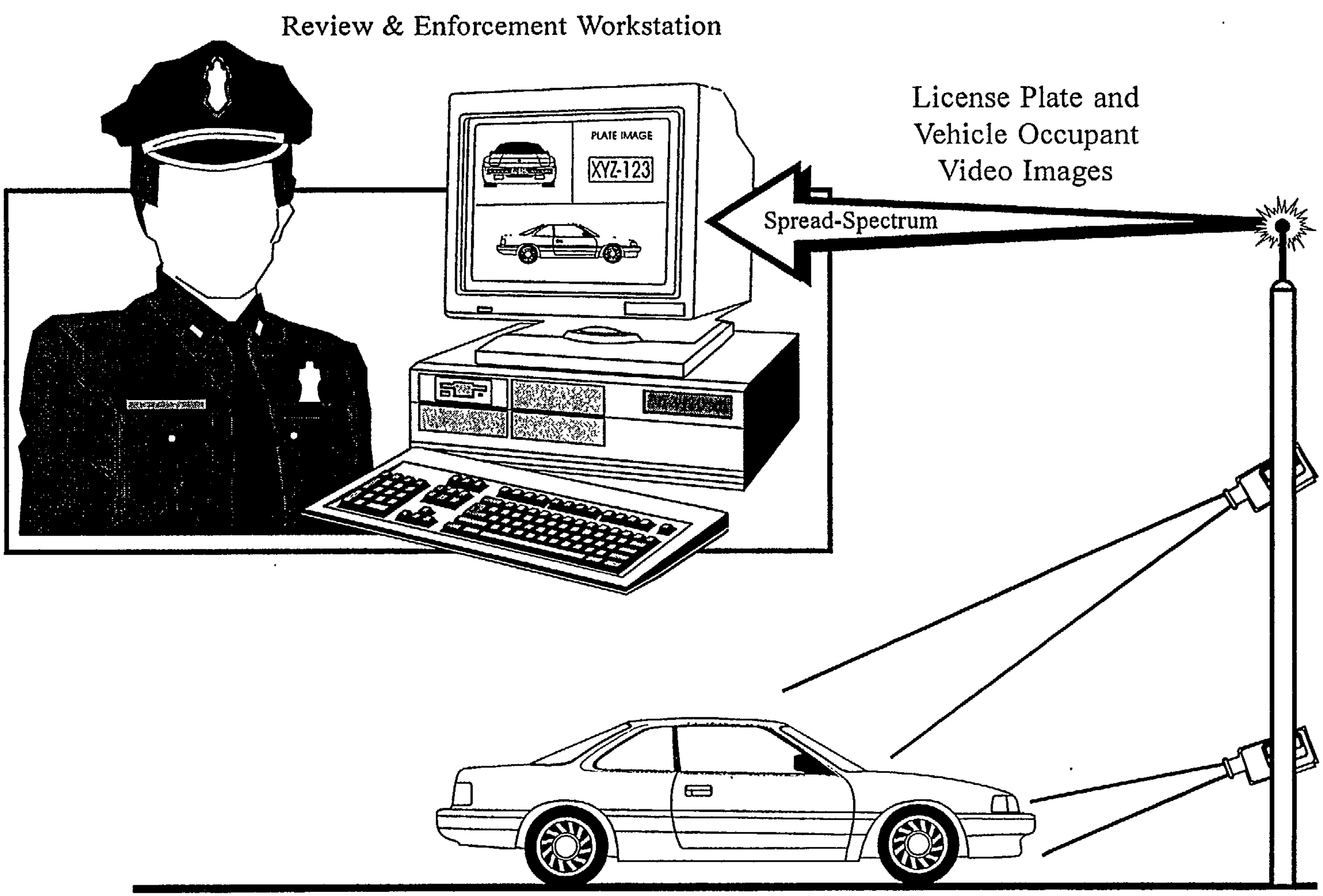

Figure 1. Conceptual Schematic of the HOVER System in Dallas, Texas

STATUS OF THE PROJECT

TTI is currently working with Transfomation Systems, Inc. on procuring and installing the equipment associated with the HOVER system. Installation of the system should occur in mid-1996, with operational testing beginning later in the summer. A twelve-month operational test will be used to evaluate and refine the enforcement procedures. The results of the operational test should prove useful to the DART and other agencies with the responsibility of enforcing HOV lanes.

DISCLAIMER

The study reported in this paper is sponsored by the Texas Department of Transportation, Dallas Area Rapid Transit, Federal Highway Administration, and Federal Transit Administration. The opinions and conclusions expressed or implied are those of the authors, and do not necessarily represent those of the sponsors.

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USE OF VIDEO-BASED TRAFFIC DATA COLLECTION AND DETECTION IN TEACHING, RESEARCH, AND APPLICATIONS

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DESCRIPTION OF LABORATORY AND FIELD EQUIPMENT

The University of Idaho's National Center for Advanced Transportation Technology (NCATT) concentrates on two main areas of transportation technology: vehicle technology and tragic systems technology. Vehicle technology areas include research related to electric batteries, hybrid electric vehicles, alternative fuels, power trains, and materials. In the traffic systems technology areas, NCATT has developed expertise in video traffic detection, traffic control and operations technology, highway design, and highway materials. This paper will concentrate on the traffic related technology.

NCATT has two traffic laboratories namely, the Machine Vision Laboratory and the Traffic Controller Laboratory. The Machine Vision Laboratory includes six Autoscope work stations. Two Peek video tracking work stations will be installed shortly. Also, the laboratory is equipped with portable equipment for initial studies before cameras are permanently installed on site. This equipment consists of video cameras and portable telescoping masts. The video equipment includes four video cameras, two televisions, one video converter, two portable masts, four camera panners, three camera panner emotes, three line splitters, and two television power wires. The masts are extendable to thirty feet (I).

The Traffic Controller Laboratory has a TCT traffic controller assembly mounted in a full size cabinet connected to a display board for instruction and demonstration and a LMD 8000 traffic actuated controller unit with supported software.

Initially, the portable video camera equipment is used to locate the best location to install permanently mounted cameras on site. The portable video cameras are mounted at different heights on the portable masts and located at different locations. For example, the intersection of Sixth Street and Washington Street was selected as a field site in Moscow, Idaho. After an extensive field data collection using the portable video equipment, a permanent location was chosen and permanent video cameras were installed on site with the help of Idaho Transportation Department personnel. Video images are now transferred from the intersection live to the laboratory using both spread spectrum video transmission and telephone line transmission.

VERIFICATION OF TECHNOLOGY IN A VARIETY OF SETTINGS AND CONDITIONS

The Autoscope system was evaluated based on a comparison between the Autoscope test results and actual observed traffic counts. The intersection evaluated in this study is Sixth Street and Washington Street in Moscow, Idaho. Washington Street is a one-way street heading in the northbound direction. Sixth Street is two-way street running east-west. The video cameras have been installed on the three approaches. Figure 1 shows a schematic diagram of the intersection and the camera locations.

Extensive data collection and analysis have been conducted for this study in order to identify the best detector layout during different times of the day (2). The data collection was taken under during three different time periods of the day in September 1995. Data were collected for each time period for two hours, daytime between 3:30 pm and 5:30 pm, day/night transition between 6:30 pm and 8:30 pm, and nighttime between 10:00 pm and 12:00 midnight. Video images of live traffic data were transmitted via radio signals to the Machine Vision Laboratory. The Autoscope system was used to record these traffic counts. Manual counts were extracted using the Traffic Data Input Program (TDIP), developed by NCATT. TDIP is computer software developed to extract traffic volume data from observing video images on a monitor and pressing the appropriate key on the computer keyboard for each turning movement (3). In the first phase of the study, traffic counts were collected using portable loops counters at the three intersection approaches. However, these loop counts were not reliable for a long data collection period due to loop breakage and vandalism (2).

In this study, a total of twenty seven diierent tests were conducted including eleven tests during the daytime period, nine tests during the night transition, and seven tests during the night time period. The main variables in these tests are the detector layout configuration, night reflection and shadow processing, and the detector thicknesses. The test results show that in general, for daytime periods, the Autoscope produced values higher than the actual counts recorded by TDIP. Table 1 shows the comparison result of the best detector layout configuration for the daytime period.

TABLE 1. TEST RESULTS FOR DAYTIME PERIOD

Measurement	EBTH	EBLT	NBRT	NBTH	NBLT	WBRT	WBTH
Actual TDIP	594	348	438	427	760	146	315
Actual AUTO	597	382	461	484	774	156	343
Actual Difference	3	34	23	57	14	10	28
Percent Error	0.5	9.8	5.3	13.3	1.8	6.8	8.9

The day/night transition period, two hours, has been analyzed in two parts, part one reflecting the first hour which represents conditions closer to the daytime period, and the other part is the second hour which represents conditions more like the night period. Tables 2 and 3 show the best result for the nine day/night transition period for the first hour and the second hour respectively (2).

TABLE 2. TEST RESULTS FOR THE NIGHT TRANSITION - First Hour

Measurement	EBTH	EBLT	NBRT	NBTH	NBLT	WBRT	WBTH
Actual TDIP	169	91	128	116	297	51	107
Actual AUTO	169	96	122	122	289	49	105
Actual Difference	0	5	6	6	8	2	2
Percent Error	0.0	5.5	4.7	5.2	2.7	3.9	1.9

TABLE 3. TEST RESULTS FOR THE NIGHT TRANSITION - Second Hour							
Measurement	**EBTH**	**EBLT**	**NBRT**	**NBTH**	**NBLT**	**WBRT**	**WBTH**
Actual TDIP	138	73	104	96	235	38	81
Actual AUTO	143	84	107	88	231	47	90
Actual Difference	5	11	3	8	4	9	9
Percent Error	3.6	15.1	2.9	8.3	1.7	23.7	11.1

The best result of the night time tests is summarized in Table 4. This detector layout works relatively well for both the day/night transition and night time periods (2).

TABLE 4. TEST RESULTS FOR THE NIGHT TIME PERIOD							
Measurement	**EBTH**	**EBLT**	**NBRT**	**NBTH**	**NBLT**	**WBRT**	**WBTH**
Actual TDIP	98	42	52	70	121	12	34
Actual AUTO	107	45	56	104	127	13	35
Actual Difference	9	3	4	34	6	1	1
Percent Error	9.2	7.1	7.7	48.6	5.0	8.3	2.9

In summary for this particular study, the following criteria should be met in order to obtain most of the Autoscope accuracy:

- Small changes in the video image, such as a passing bicycle, can be detected by the Autoscope.
- In case of heavy pedestrian volumes, detectors should be placed away from the crosswalk to prevent a passing pedestrian from setting off the detectors.
- Inconsistent backgrounds tend to provide poor results for detectors, for example, the presence of painted markers on the pavement near to the stop bars tend to restrict the placement of the detectors.
- Lanes shadowed by other lanes tragic tend to give poor results, like a center lane bordered by heavy tragic side lanes, because of reflections, shadows, and heavy vehicle occlusion.
- Left turn vehicles might cut-across most of the left lane on the crossing approach, which sets the detectors off.
- Shadows from street trees might set detectors off.

- Detection accuracy can be increased by using thicker detectors.
- Night reflection processing, shadow processing, and detector thickness are good features in Autoscope. The night reflection processing improves the Autoscope's abiity to differentiate between headlight reflection and vehicles to make more accurate counts. The shadow processing helped in differentiating between moving shadows and vehicles. Finally, the wider detectors have better accuracy rate.
- Setting the time of the day and the direction of the shadow correctly are crucial in using the Autoscope system so that shadow processing is done correctly.
- It is important of using the proper latitude and longitude settings for the site where the Autoscope is to be installed.
- Autoscope has the option of viewing up to four video images each displayed on one quarter of the screen, using a single screen camera versus a four-quad screen will help improving the detection accuracy by using wider detectors.
- During the day/night transition period, the sun light during sunset was reflecting on the camera lens. Installing a sun shield devices would help reduce this problem.
- During night period, it is observed that the flashing lights of an emergency vehicle will set the detectors off.

As a result of this study, the three best layout configurations were identified, one for each time period. However, practically in the field, only one detector layout configuration is used by Autoscope. Figure 2 shows the final detector layout that will be used during all time periods.

COLLECTION OF BASIC TRAFFIC DATA

The Autoscope system was used to collect a variety of standard traffic data including flow rate data for freeway, unsignalized intersections, and signalized intersections, and saturation headway data and detector call data at signalized intersections. These projects were funded through the ITD and the National Cooperative Highway Research Program.

Freeway Traffic Flow Data:

One of the main reasons for developing the Autoscope system was to monitor and control freeway traffic. One research project conducted using video image technology is to evaluate the Autoscope measurements versus manual tragic counts. The main elements in this project are to identify the best detector layout configurations and camera angles. Video data were collected from two sites on I-84 in Boise, Idaho. The variables in this test were (1) the direction of traffic movements, away from the camera or toward the camera, (2) layout of the detectors, perpendicular to the traffic flow - horizontal detectors or parallel to the traffic flow - vertical detectors. The Autoscope volume counts were compared with the manual counts extracted from the Traffic Data Input Program (TDIP). The results of this test is summarized in Table 5.

For best results, the cameras should be mounted in a way that the traffic flow is away from the camera and the detector orientation is horizontal. Detailed research results can be found in Transportation Research Record 1412 (4).

TABLE 5. FREEWAY FLOW DATA				
Category		Number of Sites	Error Rates	
Traffic Direction	Detector Orientation		Deviation	Mean
Away from the Camera	Horizontal	8	0.6 - 9.3 %	3.9625 %
Toward the Camera	Horizontal	4	1.8 - 13.1%	7.8250 %
Away from the Camera	Vertical	1	24.1 %	

Saturation Headway Data:
NCATT researchers are currently experimenting with the Autoscope system to observe saturation headways. At one heavy flow intersection, U.S. Highway 8 and Farm Road, in Moscow, Idaho, the portable video camera equipment was stationed during the afternoon peak hour. The Autoscope was used to detect vehicle passage over two detectors, one at the stop bar and the other at some distance behind the stop bar. Figure 3 shows a schematic diagram of the intersection, mast position, and possible detector locations. There are no results at this time for this particular test, however, preliminary results of saturation flow tests conducted at the same intersection are presented in Table 6. These data were collected during a 15-minute period (5).

TABLE 6. PRELIMINARY SATURATIONFLOW MEASUREMENTS				
Measurement	Eastbound		Westbound	
	Headways (sec)	Saturation Flow Rates (vph)	Headways (sec)	Saturation Flow Rates (vph)
Maximum	3.85	3623	3.68	2629
Minimum	0.99	934	1.37	978
Average	2.22	1624	2.09	1723

Autoscope Signal Call:
The ability of the Autoscope system to correctly send a call to the traffic signal controller when a vehicle is present at the stop **bar** of an intersection waiting for service is an important function of the video detection system. This study has been conducted by performing four tests during the day/night transition period. A video tape for each test was manually inspected tp determine the presence or lack of a vehicle on each approach during each phase throughout the duration of the tape. The study intersection has a two phase cycle. For each phase, whether or not a vehicle was recorded at the

beginning of each green phase was noted. The traffic controller receives a detection call during the red phase if a vehicle is present. During this study, two main sources of errors were identified: (1) the Autoscope does not send a call when there is a vehicle waiting at the stop bar, and (2) the Autoscope sends a call but there is no vehicle waiting. The first error was more serious, due to the fact that the vehicle is waiting for service while its' phase has been skipped. The second source of error is of less concern, except that it increases the cycle length slightly. The overall average results of the four tests are summarized in Table 7 (2).

TABLE 7. AUTOSCOPE SIGNAL CALL

Approach	Percent Errors			
	Veh-Det[1]	No Veh-No Det[2]	Veh-No Det[3]	No Veh-Det[4]
EBTH	**23.5**	**61.1**	**3.8**	**11.4**
EBLT	**24.3**	**62.5**	**6.2**	**6.8**
EB Approach	**41.6**	**44.5**	**4.3**	**9.6**
NBRT	**53.4**	**33.2**	**5.9**	**7.3**
NBTH	**50.8**	**25.9**	**18.5**	**4.7**
NBLT	79.1	7.0	11.7	2.1
NB Approach	96.9	1.1	1.9	0.0

1 vehicle present and the Autoscope detected a vehicle
2 no vehicle present and no detection from the Autoscope
3 vehicle present and no detection from the Autoscope
4 no vehicle present and the Autoscope detected a vehicle

All approaches show satisfactory results with the exception of the NBTH movement where more than ten percent of the time there was a vehicle present but the Autoscope failed to detect it. However, the overall NB approach has very good results.

APPLICATION OF VIDEO TECHNOLOGY TO DESCRIBE MORE COMPLEX CONDITIONS

Vehicle Size Data:

While the Autoscope was specifically designed to detect vehicles passing on a freeway or through an intersection, the UI-NCATT developed several other applications, including the measurement of vehicle height and length. It was of interest to the ITD to monitor vehicles traveling through ports of entry to determine if they meet legal size requirements.

For this test, actual trucks heights were recorded using a standard measuring rod. Trucks were videotaped crossing the port of entry by a video camera mounted on one side of the street and oriented to see a light post across the street. The light post was marked in 0.3 meter increments, the detector locations for the Autoscope. Figure 4 demonstrates the site installation layout. The passage of a truck image triggered the detectors and the Autoscope recorded the corresponding time of these activations. The maximum number of activated detectors is correlated to the height of the truck. Figure 4 illustrates the truck passage profile. This study showed that the Autoscope measurement accuracy was within a 10 percent margin of error for 70 of the 79 trucks studied. Table 8 shows the distribution of percentage errors for the truck height measurements *(4)*.

TABLE 8. TRUCK HEIGHT MEASUREMENTS

Percent Error	< 5%	5 - 10%	10 - 15%	15 - 20%	> 20%
Number of Trucks	48	22	3	2	4

Another test conducted by NCATT researchers was to measure truck length. This test was similar to that measuring truck heights with the exceptions that the detectors were located along the path of the trucks and the maximum number of detectors activated simultaneously represent the truck length. A correlation coefficient of 0.85 between the number of the Autoscope activated detectors and the actual measured truck length was observed indicating a good fit.

Turning Movement Counts:

The intersection is a vital unit of an urban network. Designing and analyzing traffic operations at an intersection is one of the most complicated tasks in traffic engineering. All traffic approaching an intersection shares the same space, therefore, to avoid conflict these vehicles must be separated by time. Traffic control devices, STOP control and traffic signal control, must then be used. Traffic volumes using the intersection are the main determining factor for which traffic control device should be installed, STOP sign or traffic signal.

Using video technology to measure traffic movement counts, the vehicle should be traced by detectors to identify its path, e.g., through movement or left/right turning movement. Detectors are placed on each arriving and departing approach, as seen in Figure 5. The time difference between to consecutive detector activations are recorded. A northbound through movement, for example, is identified by the activation of detectors 0 and 4, while a northbound left turn movement is identified by the consecutive activations of detector 0 and 6. Similarly, a northbound right turn movement is identified by activating detector 0 and 5. This postprocessing of the Autoscope data has many more applications than just counting turning movements. It can also be used in delay studies and queue length estimation *(4)*.

Experimental tests at four intersections controlled by STOP signs was conducted in Pullman, Washington and Moscow, Idaho. The traffic counts of Autoscope were compared with the manual counts using the Traffic Data Input Program (TDIP). The findings of these tests showed that the camera placement and viewing angle are essential elements for a successful test. The Autoscope system requires an unobstructed view of all vehicle paths and the detectors should be laid out in a fashion that pedestrian crossing will not activate the detectors.

USE OF VIDEO TECHNOLOGY IN INSTRUCTION

The University's Machine Vision Laboratory, in conjunction with the instrumented intersections located in Moscow, provide a tremendous opportunity for students to learn about both data collection and tragic control using video. Since 1991, various components of the transportation engineering curriculum have included the use of these video facilities.

- Students have used the portable mast to record departing queues from a signalized intersection. The video taped was analyzed by the students and saturation headways data were extracted.

- Laboratory exercises have been developed to instruct both undergraduate and graduate students in the use of the Autoscope system. Students learn about optimal detector layout patterns and measure detection accuracy. Students also learn about the importance of field of view in placing a video camera to record a traffic scene.

- Students have developed simple algorithms to measure vehicle speeds using postprocessed Autoscope data.

CONCLUSIONS

In this paper, initial results showing the potential of using machine vision technology as a tool in the traffic engineering profession were presented. The Autoscope system was evaluated based on a comparison between the Autoscope test results and actual observed data on diierent applications other than traffic detection.

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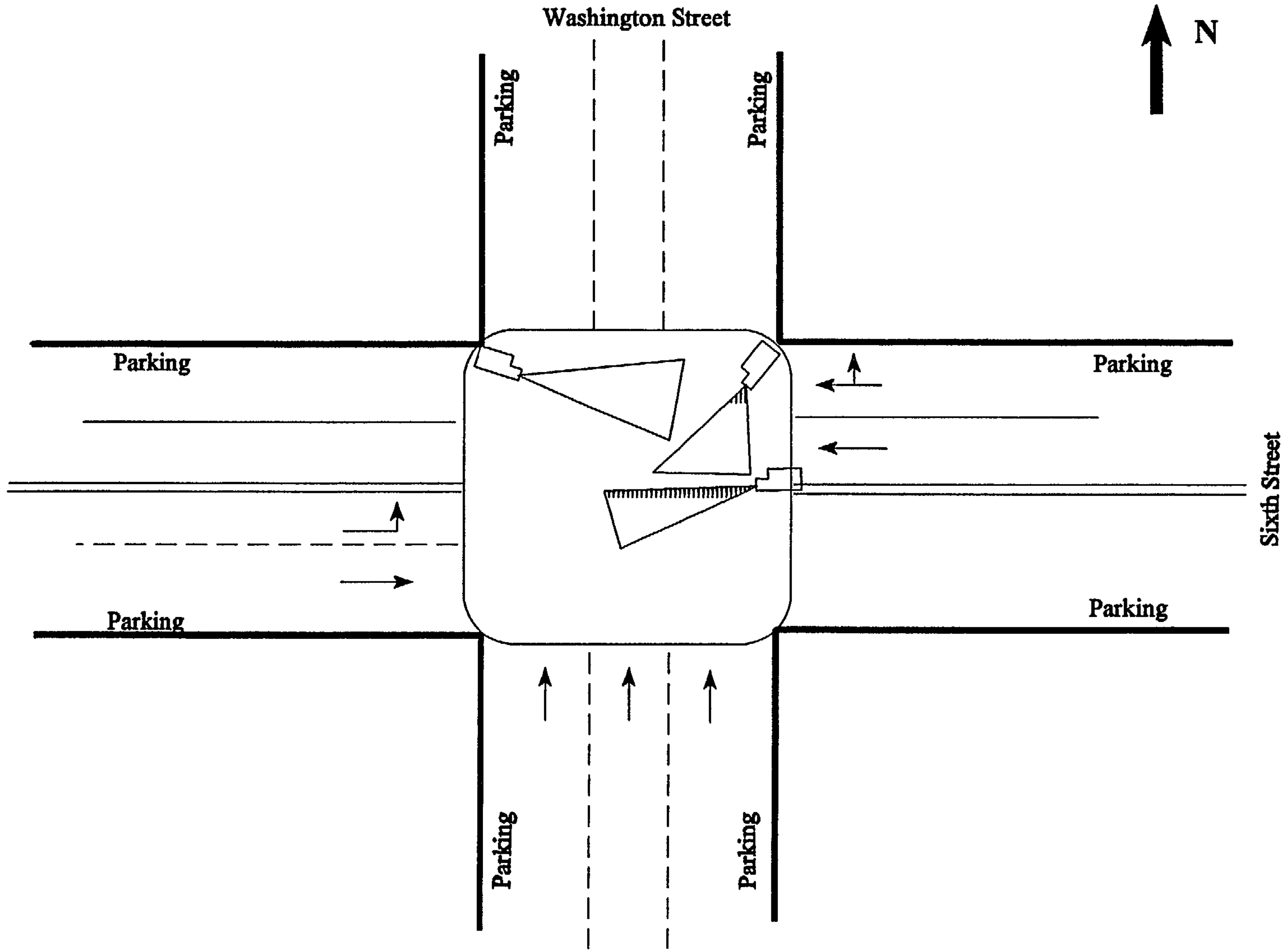

Figure 1. Schematic Diagram of Sixth Street and Washington Street Intersection

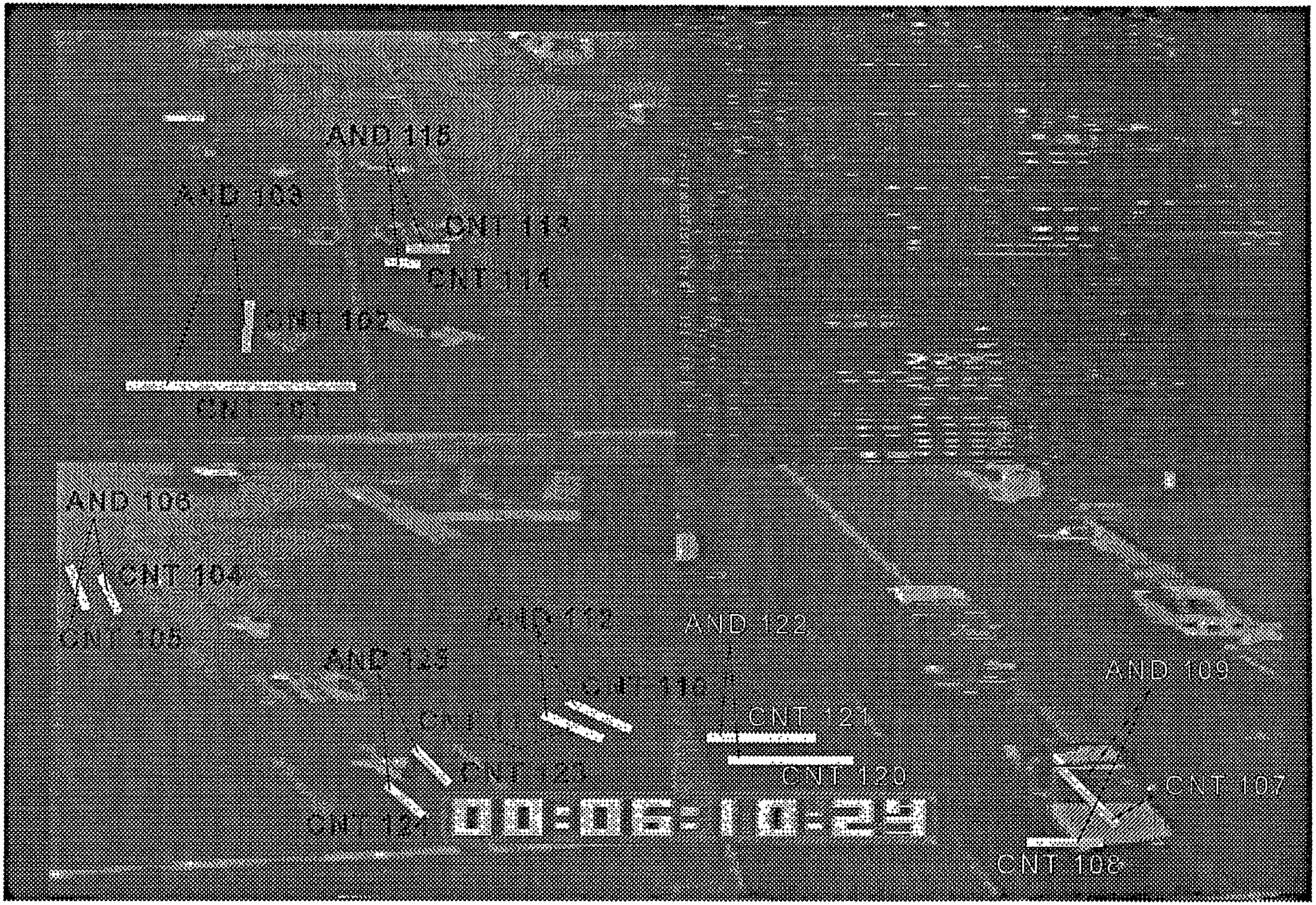

Figure 2. Detector Layout Configuration

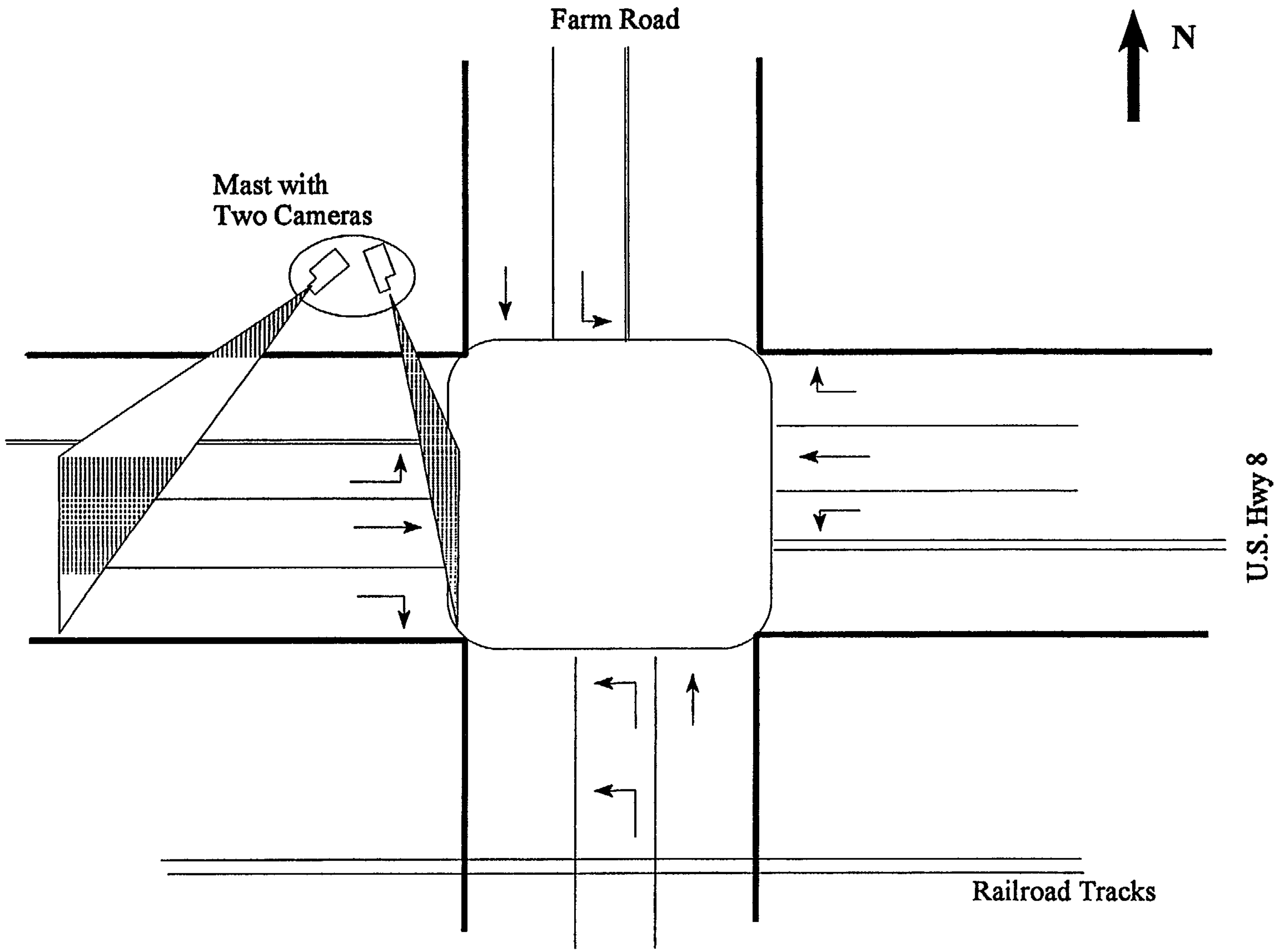

Figure 3. Schematic Diagram of U.S. Hwy 8 and Farm Road Intersection

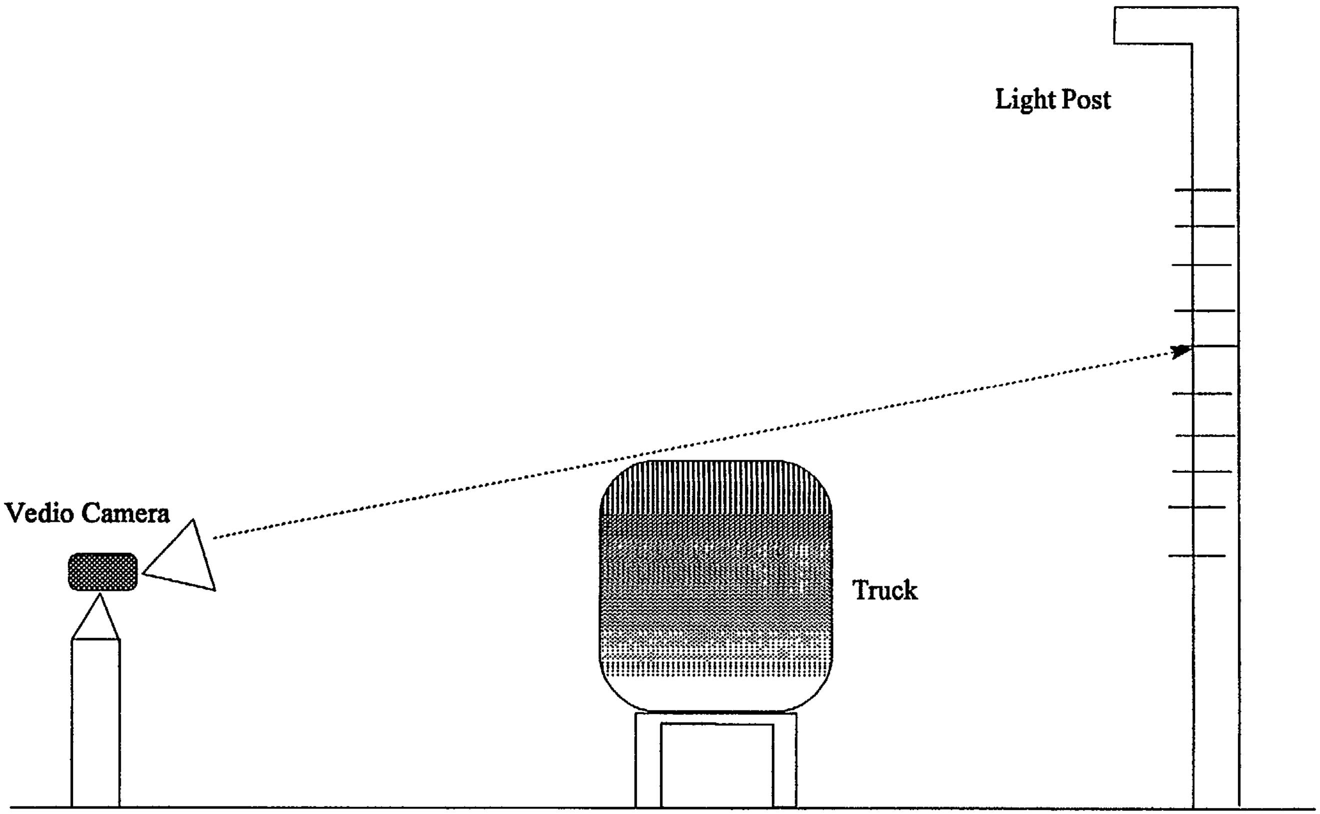

Figure 4. Cross Section for Truck Hight Measurement

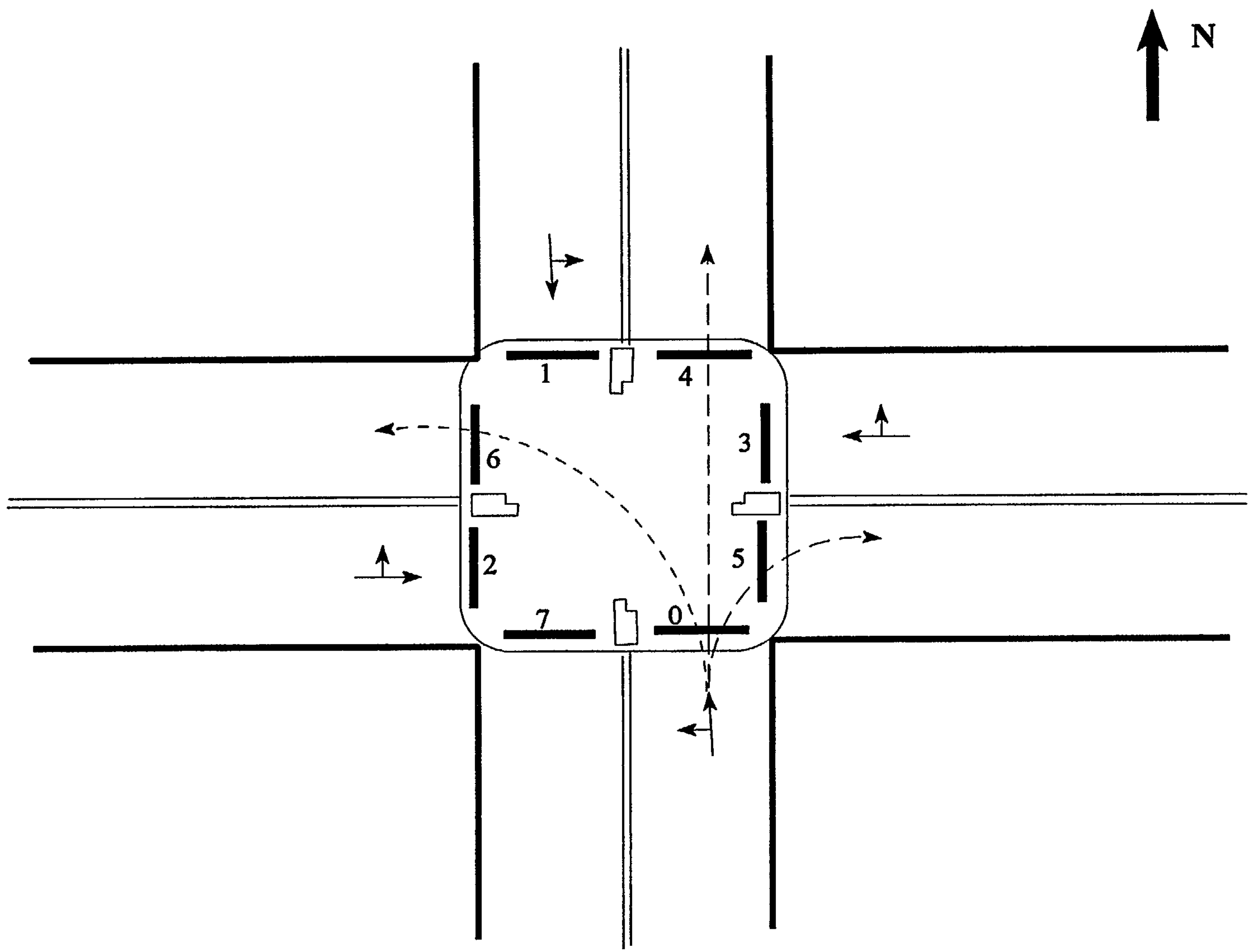

Figure 5. Autoscope Detector Layout for Turning Movement

DEMONSTRATION OF VIDEO-BASED TECHNOLOGY FOR AUTOMATION OF TRAFFIC DATA COLLECTION: TIME, ORIGIN-DESTINATION AND AVERAGE VEHICLE OCCUPANCY

(EXTRACTED FROM A REPORT PREPARED FOR HILLSBOROUGH COUNTY METROPOLITAN PLANNING ORGANIZATION)

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Presented at
National Traffic Data Acquisition Conference
Albuquerque, New Mexico

May 5-9, 1996

Demonstration of Video-Based Technology for Automation of Traffic Data Collection

Executive Summary

This report documents the findings of a field demonstration project that was conducted to evaluate the feasibility of a video-based traffic data collection process, compatible with traffic performance measures needed for the Hillsborough County Congestion Management System (CMS). As these systems mature, greater reliance on real-time traffic performance data will be required for regular (and even continuous) monitoring of the transportation system. Automation of traffic data collection through video-based technology can satisfy this requirement in a cost-effective manner.

Traditionally, traffic data collection has been very labor intensive, even when capturing relatively small sample sizes (discussed in the introduction of this report). This attribute of conventional data collection has also discouraged the level of traffic data collection frequency that is essential for performance monitoring. License plate matching has long been used by transportation engineers and planners as a source of data for origin-destination travel time and other traffic studies. Typically, these studies have required large numbers of field staff and associated costs. Also, manual operations have often been characterized by unacceptably high rates of error in data collection and processing, especially when large amounts of data need to be collected and analyzed in a short period of time. Many of the shortcomings associated with the manual collection and processing of data from vehicle license plates can be overcome through the use of video camcorders and machine vision license plate readers. Modern video camcorders are capable of capturing very clear images of license plates on vehicles operating in high-speed, high-volume traffic, and these images can be converted (without human processing fatigue in one-tenth the time of manual processing) to computer files by license plate readers with high levels of speed and accuracy. Video images can also be captured for vehicle occupancy counts to improve sample size and accuracy over manually-collected counts.

Over the three-day, A.M. peak-period evaluation (six total hours of traffic performance monitoring), this field demonstration found that video-based traffic data collection compared to manually-collected traffic data resulted in a total of ***2,746*** (almost ***400*** percent) more usable observations, each requiring about seven minutes less time to collect and process, at a cost of only 50 cents per unit more. The more expanded, real-time sampling capabilities of video-based collection also facilitated the creation of more meaningful traffic performance measures (e.g., 15-minute volume versus average vehicle occupancy, E-minute volume versus average travel speed, and total person-trips) at specific points or by movement within the transportation system.

This field demonstration has concluded that automation of traffic data gathering and analysis is feasible through video and machine vision technology application. This type of ITS technology satisfies a need of congestion management systems-real-time monitoring. As a result, more meaningful traffic performance data can be collected in a more cost-effective manner, and utilized more often in the transportation decision making process.

Overview

This report documents the findings of a field demonstration project that was organized and conducted to evaluate the feasibility of a video-based technology application in the automation of traffic performance data gathering and analysis. This field demonstration was coordinated with the Hillsborough County Metropolitan Planning Organization (MPO) to investigate a data collection automation application that is compatible with traffic performance measures needed specifically for the Hillsborough County Congestion Management System (CMS).

During the early years of Hillsborough County's CMS, available traffic data were utilized to evaluate the performance of the transportation system. However, since the CMS is expected to gradually place a greater reliance on real-time traffic performance data collected more often at more locations, development of a customized, real-time traffic performance monitoring system n-ill ultimately be needed. According to Lucilla Ayer, Executive Director of the Hillsborough County MPO, "We need to continue to explore new ways to monitor and evaluate traffic congestion in urban areas. The application of ITS technologies to data collection and analysis certainly can enhance our current methods, resulting in greater mobility planning and design." CUTR believes that CMSs will require cost-effective automation of traffic performance data collection and analysis, and so the time to evaluate potential automation techniques is imminent.

This report includes a background discussion of the more conventional (and traditional) techniques for collection of travel time, origin-destination, and average vehicle occupancy data; a discussion of comparative advantages and disadvantages of each technique; and findings of the video-based automation compared to effectiveness of collecting the same information through visual observation at each camera location.

Introduction

Intelligent Transportation Systems (ITS) represents the utilization of technology (e.g., information processing, communications, control, and electronics) to improve safety, reduce congestion, enhance mobility, minimize environmental impact, save -energy, and promote economic productivity in our transportation system. Congestion Management Systems, one of the six transportation management systems stipulated in the Intermodal Surface Transportation Efficiency Act (ISTEA) of 199 1, are intended to serve as decision-support tools that provide information on transportation system performance and alternative improvement strategies. ISTEA requires each state to develop and implement the six transportation management systems, along with a Traffic Monitoring System for Highways.' The Interim Final Rule (IFR) on the ISTEA (December 1, 1993 mandated that all Transportation Management Areas (areas with a population more than 200,000) that are non-attainment for ozone and/or carbon monoxide should have an operational CMS by October 1, 1995.[2] Further, according to the "Florida ISTEA," all MPOs in Florida are required to establish a CMS. Recent guidance from the United States Department of Transportation states that the deadline for a fully operational CMS has been postponed to October 1, 1997. Title II (Transportation Funding Flexibility), Section 205, legislation now authorizes that a state can elect not to implement, in whole or in part, one or more of the ISTEA management systems. Moreover, indications are that Florida will retain CMS requirements. Nevertheless, Congestion Management Systems are important because of the increasing skepticism concerning the addition of capacity alone to alleviate congestion and enhance mobility. Many in the transportation industry today believe that ITS technologies hold the potential to "get more out of our existing transportation systems."

CMSs require a continuous program of traffic data collection and system monitoring. These data will be used to evaluate the duration and magnitude of congestion and to evaluate the effectiveness of any implemented CMS strategies. Thus, compliance with ISTEA requires that a great deal of accurate and timely traffic data be collected. The usefulness and success of a CMS will depend on the accuracy and timeliness of the traffic performance data collected, the ease of obtaining and analyzing the data, and the measurability of the data against predetermined CMS objectives.

To assist Florida's MPOs and the state in developing effective and efficient congestion management systems, CUTR and the Hillsborough County MPO conducted a field demonstration to evaluate the feasibility of a video-based technology application for the automation of traffic performance data gathering. When compared to conventional techniques for traffic data collection, automation provides greater accuracy and reliability and is much less labor intensive (thereby eliminating or reducing human error). According to industry estimates, the total cost of automated data collection can be up to 30 percent less than manual traffic data collection, over the long term. Furthermore, a large portion of the automated data collection cost (up to 75 percent) is generally attributed to the up-front, one-time capital investment in the equipment required for automation.[3]

Authorities realize that there is an increased need for data and that not enough data are currently collected. For example, planners with the Georgia Department of Transportation:

> "clearly desired more data than is currently available to them . . . types of data commonly desired were:
>
> - average speed or travel times for all significant roads,
> - extensive and current origin and destination data for the metropolitan areas, and
> - vehicle occupancy data for the major roadways, especially in the metropolitan area."[4]

Information on the discussion of conventional traffic data collection contained in this report was gathered through an extensive literature search and by contacting various state agencies and transportation consultants. Information on the video-based automated technique was collected first-handduring this field demonstration and through literature search of other evaluations. This field demonstration was conducted with the participation of Transfomation Systems, Inc. (Houston, Texas) and Computer Recognition Systems, Inc. (Cambridge, Massachusetts), who supplied state-of-the-art video and machine vision equipment, and the Hillsborough County CMS Task Force, who helped assess traffic data collection needs.

CONCURRENT SESSION 9A - EMERGING TECHNOLOGIES

Presented at
National Traffic Data Acquisition Conference
Albuquerque, New Mexico

May 5-9, 1996

OBSERVATION BALLOON SYSTEM

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Presented at
National Traffic Data Acquisition Conference
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May 5-9, 1996

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OBSERVATION BALLOON SYSTEM

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It is clear that we can no longer "build" our way out of the growing dilemma of "'gridlock". Federal initiatives such as ISTEA are requiring States to invest more time and effort into getting the most out of the existing transportation system. New and innovative tools must be developed to extract the maximum capacity from each of our roadways. DelDOT, in conjunction with FHWA., is evaluating the effectiveness of one such innovative tool, Rafael's Observation Balloon System (OBS).

Traditionally, a comprehensive view of a road network's operation has been achieved through the use of manned aircraft or stationary permanent mounted camera systems. By using these devices, signal progression can be observed for the entire area two dimensionally, not just linearly as would be observed by a driver along a given roadway or by an observer at a fixed point. Similarly, incidents and congestion can be monitored for the road network as a whole, simultaneously.

While manned aircraft or fixed cameras provide a wealth of information, they require a highly skilled team to provide that data. The use of an Observation Balloon System that can be quickly deployed to any location with minimal staff provides the same data at a fraction of the cost. The OBS shares the advantage of manned aircraft in mobility and wide field of view, yet does not have the expense of a flight crew. Similarly the OBS can provide the permanent records obtained from a fixed camera system yet not be liited to a fixed location.

The current status of the Observation Balloon System being evaluated will be presented at the National Traffic Data Acquisition Conference.

FEASIBILITY OF USING SIMULATED SATELLITE DATA COORDINATED WITH TRAFFIC GROUND COUNTS

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The Ohio State University
Authors: Carolyn J. Merry, et al.
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Presented at
National Traffic Data Acquisition Conference
Albuquerque, New Mexico

May 5-9, 1996

Feasibility of Using Simulated Satellite Data Coordinated with Traffic Ground Counts

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ABSTRACT

Synoptic coverage provided by a satellite would allow more coverage of a region, and when combined with traditional ground counting methods, would give improved estimates of traffic characteristics. Commercial companies will be providing fine resolution satellite data in the very near future. To prepare for such data sets, we report on results obtained from an aircraft overflight with results obtained from traffic ground counts coordinated in time. Several comparative traffic measures, such as flow rates, densities, levels of service and velocities of vehicles, were developed.

INTRODUCTION

Fine resolution satellite data could provide improved spatial coverage and resolution that would complement existing traffic data collection systems. Synoptic coverage provided by a satellite would allow more coverage of a region, and when combined with traditional ground counting methods, give improved estimates of traffic characteristics. If a satellite could provide repetitive coverage for a wide swath area, while counters are providing temporal data on vehicle movement, the spatial coverage of the road network would be greatly improved. In addition to providing more data on segments *where* there are counters, satellite *snapshots* at specific times could tie traffic characteristics on highway segments with no automatic counters to those highway segments with counters to estimate spatial variability among roads. If this spatial variability were assumed constant (or otherwise known) in time, the satellite data could be used to extrapolate traffic characteristics from the highway segments with continuous ground counts to those without such counts during periods when there is no satellite coverage. Satellite views could also be used to test whether segments where no data are gathered using mechanical counters have traffic characteristics similar to other segments in their traffic data monitoring class; if they are not, the categories could be refined. These *snapshots* could also be used to identify troublespots for either temporary or permanent deployment of traffic counters. Moreover, satellite measurements are safer, since fewer personnel would be required to interfere with vehicle traffic to install and operate ground measurements.

We previously found that 1 m resolution was sufficient for counting and classifying vehicles at accuracies of 90% for highway segments tested in the Columbus, Ohio, area (1, 2). Considering that panchromatic imagery would not be possible at night or in cloudy conditions, we estimated that with l-m resolution, a satellite would cover approximately 0.4% of the highways in the continental United States per day. If the resolution could be increased to 3 m and still maintain acceptable accuracy, the coverage would be 2.7%, or increased by a factor of more than six (3). Other than the spatial resolution, the critical parameter appears to be the data transmission rate for such a satellite sensor.

These findings are important as commercial companies will be providing fine resolution satellite data in the very near future (4). For example, the EarlyBird satellite launched by EarthWatch, Inc. will provide for 3 m panchromatic data for the fall of 1996. The QuickBird satellite, also launched by EarthWatch, Inc., will provide for 1 m panchromatic data in the spring of 1997.

UNRESOLVED ISSUES

There are several unresolved issues that need to be considered. Our findings need to be confirmed with real satellite data coordinated with the traffic data counts. We plan to do this in the fall 1996 when the 3-m resolution data is available and continue our analyses in the spring, 1997, with the l-m panchromatic data.

Another issue is how to merge *temporally-rich* ground counts with spatially-rich satellite data. Traditional traffic data instruments record data *24* hours a day for several days, but for limited highway segments; *i.e.*, they are poor *in space*. How does one take data sets for limited locations and extrapolate them to other similar classed highways that would be covered by satellite data providing a large area1 coverage, but is poor *in t ime?*

The third issue is to prepare for the needed ground processing infrastructure to use satellite data operationally in state traffic monitoring activities. The tasks for using satellite data in traffic activities must run smoothly. Use of fine-resolution satellite data is relatively new for state transportation agencies. Incorporating this information source easily into existing agencies has to be demonstrated. The satellite data will not replace the ground-based measurements, but can provide supplemental information that was previously not available to transportation agencies.

APPROACH

As a follow-on to our previous work, we felt it important to take advantage of the scheduled fine-resolution launches. To plan for this imminent effort, we simulated tests by investigating results obtained from an aircraft overflight with results obtained from traffic ground counts coordinated in time. Also, we needed to develop the initial infrastructure necessary for using such fine resolution satellite data in the future.

A field test program was developed to help address these unresolved issues. The objectives of our field test program were to determine several comparative measures from the ground and aircraft data sets. These measures included flow rates, densities, velocities, and levels of service.

Another comparison was to determine the spatial-temporal limits of our data sets. In this way we could determine the limit of accuracy of both the ground and aircraft data sets. In our comparisons, the final objective was to automate the process as much as possible.

The image processing tasks had been automated before with tests performed for several sites around Columbus, Ohio (1). These programs would be used to determine their usefulness under different conditions. For cases where the programs did not perform as expected, the technical issues would be identified for future work.

Three data sets were obtained around Columbus on 30 November 1995. The sites included I-270 on the west side of Columbus, I-70 just west of Columbus, and I-71 just south of Columbus. Traditional ground counts were obtained from the Ohio Department of Transportation (ODOT) Bureau of Technical Services. Two types of sensors were used to collect the ground counts – automatic traffic recorders (ATR) that collect volume by length (three classes of vehicles) data in one-minute intervals and weigh-in-motion-based (WlM) sensors that collect speeds and presence of FHWA class vehicles with a time stamp. Concurrent aerial photographs were obtained by the ODOT Bureau of Aerial Engineering at a scale of 1 in. = 400 ft. In addition, we video-taped the traffic from the ground to provide on-site ground truth during data acquisition.

The aircraft photos were scanned at a 0.5-m resolution and then aggregated to form l-m resolution data sets. These images were processed through the image processing routines to provide vehicle counts. The ERDAS IMAGINE software was used to view the results from each image processing step and to perform image enhancement.

RESULTS

The field data recorders provided us information so that we could develop several traffic measures. We report here on our preliminary results of the I-70 site, which used the ATR vehicle-by-length sensor.

Traffic flow was calculated at l-minute intervals by tracking vehicles on the aerial photographs. Speeds by vehicle class and the density of the segment were also calculated. Last, levels of service were estimated with standard procedures using the vehicle density values.

Vehicles identified on the video were matched to their estimated location (taken at the photo time) on the aerial photograph. This identification also provided a match to the traffic data recorders. We found excellent agreement between the measures calculated from the ATRs with the calculations made directly from the photographs.

Results from the automated process using image processing techniques showed that accuracies of vehicle counts for selected highway segments ranged from 60 to 87% accuracy. We were initially surprised at the lower accuracy values, as earlier results indicated accuracies of 90% for counting vehicles (1).

Our image processing routines were originally designed to process imagery that had distinctive shadows associated with each vehicle. The November date of our field test had slightly overcast conditions, producing faint or little shadows. Therefore, additional image processing was performed to accentuate the shadows. These procedures included edge enhancement techniques to sharpen the shadow edge, allowing detection by the algorithm.

Another technique that was tested included an image overlay function. Two overlapping highway segments are registered to one another; then one image is overlaid onto the another, producing a composite image. This facilitated our tracking a vehicle through a given highway segment, thus allowing us to obtain velocities by dividing the distance corresponding to a change in spatial coordinates of a vehicle by the time difference between the two photographs (in our case, 5 sec). Velocities that were calculated were within ±1 mph when compared to calculating velocities directly from the aerial photographs.

One last technique that was tested and provides promise is image subtraction. In this case the registered two overlapping highway segments are subtracted from each other. The resulting composite image contains all the changes that occurred between the two images. These changes should primarily be the vehicles that moved between the two images. This technique would also allow calculation of vehicle velocities.

CONCLUSIONS

We were tasked to determine several comparative measures from a field test program coordinated with ground measures of vehicle counts and aircraft imagery. The scanned aerial imagery data sets were analyzed to provide information on mapping and counting vehicles. We got very good results when comparing flow, density, velocities, and levels of service obtained directly from the aerial photographs to those obtained from the ATRs. We found that additional image processing was required to obtain accuracies in these data sets where less than ideal weather conditions occurred when compared to accuracies previously obtained in clear weather.

ACKNOWLEDGMENTS

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